East Asia and Pacific
EAP Critical Infrastructure Risk Assessment and Retrofitting Program

Safe and Resilient Infrastructure in the Philippines
Applications of International Experience

August 2014

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EAST ASIA AND PACIFIC
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Applications of International Experience

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The report presents the results of a detailed vulnerability assessment and summarizes the prioritization methodology developed to guide investment decisions on the strengthening of critical assets in Metropolitan Manila. With support from the World Bank, the engagement on Safe and Resilient Infrastructure has carried out a preliminary structural assessment of over seven hundred public school campuses and twenty hospitals retained by the Department of Health in Metro Manila.

The report also highlights the lessons learned from seismic retrofitting programs implemented throughout the world, as showcased during the Forum on Safe and Resilient Infrastructure that took place in Manila, Philippines, in October 2013.

The team extends special acknowledgement to the Philippines Department of Public Works and Highways and is grateful for funding support from the Australian Government and the Global Facility for Disaster Reduction and Recovery (GFDRR).
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<td>CP</td>
<td>Collapse Prevention</td>
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<tr>
<td>DepEd</td>
<td>Department of Education</td>
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<td>DPWH</td>
<td>Department of Public Works and Highways</td>
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<td>DRRM</td>
<td>Disaster Risk Reduction and Management</td>
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<td>FDD</td>
<td>Facilities Development Division (California)</td>
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<td>FEMA</td>
<td>Federal Emergency Management Agency (United States)</td>
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<td>GDP</td>
<td>Gross domestic product</td>
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<td>GoP</td>
<td>Government of the Philippines</td>
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<tr>
<td>HRMEP</td>
<td>Hazard Risk Mitigation and Emergency Preparedness Project</td>
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<tr>
<td>IO</td>
<td>Immediate Occupancy</td>
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<td>IPCU</td>
<td>Istanbul Project Coordination Unit</td>
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<td>ISMEP</td>
<td>Istanbul Seismic Risk Mitigation and Emergency Preparedness Project</td>
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<tr>
<td>JICA</td>
<td>Japan International Cooperation Agency</td>
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<tr>
<td>LS</td>
<td>Life Safety</td>
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<tr>
<td>M</td>
<td>Magnitude</td>
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<tr>
<td>MMEIRS</td>
<td>Metro Manila Earthquake Impact Reduction Study</td>
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<td>MMDA</td>
<td>Metro Manila Development Authority</td>
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<td>NSCP</td>
<td>National Structural Code of the Philippines</td>
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<td>OSHPD</td>
<td>Office of Statewide Health Planning and Development (California)</td>
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<td>PHIVOLCS</td>
<td>Philippine Institute of Volcanology and Seismology</td>
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<td>TCIP</td>
<td>Turkish Catastrophe Insurance Pool</td>
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<td>UBC</td>
<td>Uniform Building Code</td>
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<tr>
<td>WVF</td>
<td>West Valley Fault</td>
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Struggle in strong wind and driving rain produced by monsoon Pedring (Nesat) that killed about 70 people and displaced 635,405.

Photo by ArtPhaneuf/Thinkstock.com
Executive Summary

The Philippines is among the top disaster hotspots of the world. It is highly exposed to a wide range of natural hazards, including earthquakes, volcanic eruptions, and other geological hazards, as well as to typhoons and monsoon rains, all of which limit the country’s sustainable development. Over the past five years, the Philippines has experienced severe weather events resulting in considerable damage and losses. Typhoon Yolanda, which struck in November 2013, is considered among the strongest ever to make landfall, with close to 8,000 dead and missing. An initial estimate (GoP 2013) puts the total damage and loss from Yolanda at PhP571.1 billion (equivalent to US$12.8 billion).\(^1\) Catastrophe risk modeling for the Philippines (AIR/ADPC 2013) shows the country is expected to incur, on a long-term average basis, PhP206 billion (US$4.6 billion)\(^2\) per year in damage to public and private assets from earthquake ground shaking, wind and precipitation induced by tropical cyclones, and precipitation induced by nontropical cyclones (monsoons).

Over the past decade, the government of the Philippines (GoP) has taken steps to improve the overall resilience of the country to the impacts of natural disasters. For example, a multiyear risk assessment—the Metro Manila Earthquake Impact Reduction Study (MMEIRS)—estimated the physical and human losses and impacts of different earthquake scenarios in Metro Manila. The MMEIRS was implemented from 2002 to 2004 by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), the Metro Manila Development Authority (MMDA), and the Japan International Cooperation Agency (JICA) to increase the structural resilience of public assets and infrastructure in Metro Manila. It evaluated seismic hazards and the potential damage to and vulnerability of the area to various scenario earthquakes and developed a master plan for earthquake risk management. Following the release of the MMEIRS report, the Department of Public Works and Highways (DPWH) embarked on an ongoing program of retrofitting bridges in Metro Manila.

Since 2010, the GoP has focused on developing a comprehensive disaster risk management agenda. It established the policy framework for disaster risk reduction through the 2010 Philippine Disaster Risk Reduction and Management (DRRM) Act (Republic Act No. 10121), which emphasizes ex-ante actions—that is, preparedness, prevention, and mitigation—over emergency relief and response. The strategies for implementing the law are contained in the National DRRM Framework and Plan (2011–28), which identifies the high-priority areas for engagement of the sectoral agencies of the government.

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1. Bangko Sentral exchange rate of US1 = PhP44.637, as of February 25, 2014.
2. Ibid.
Since 2011, the DPWH has been engaged in technical assistance with the World Bank through the Safe and Resilient Infrastructure Program to assess the vulnerability of schools in Metro Manila, as a step toward strengthening key public buildings against earthquakes. Public schools and hospitals in Metro Manila have different levels of vulnerability to earthquakes, floods, typhoons, tsunamis, and volcanic eruptions. Under the Safe and Resilient Infrastructure Program, the DPWH has developed (1) a set of guidelines for the seismic evaluation of schools and hospitals in Metro Manila; (2) a methodology for prioritizing buildings to identify the highest risk candidates for upgrade and structural risk reduction; and (3) technical guidelines and tailored design examples for upgrading typical school buildings in Metro Manila.

The results of the prioritization show that strengthening the most vulnerable 5 percent of school buildings (186) can reduce the number of student fatalities by 25 percent (more than 6,000 lives saved). By strengthening the most vulnerable 40 percent of school buildings (1,466), potential student fatalities can be reduced by 80 percent (more than 19,000 lives saved). In other words, upgrading a relatively small number of systematically selected structures can save a disproportionately large number of lives, and it would be more cost effective than building new schools.

These findings led the DPWH to commit to implementing the cornerstone phase of a Safe and Resilient Infrastructure Program in Metro Manila. This would involve upgrading approximately 200 of the most vulnerable public school buildings, with a view toward eventually scaling up to other sectors (for example, lifeline infrastructure) and geographical locations and to institutionalizing quality assurance systems.

As the GoP formulates an initial strategy for undertaking its earthquake risk management program, international experience can provide insight into the potential challenges and key lessons of developing and implementing structural resilience programs at various scales:

- Since the early 1900s, California has invested in strengthening key assets through what is now a large-scale, multidimensional earthquake risk management program. Each major earthquake the state has faced has given the government a greater understanding of risk that has generated stronger regulatory codes, legal enactments, and structural retrofitting initiatives in schools, hospitals, and public infrastructure, such as highways, bridges, and dams. State government action has catalyzed the creation of structural strengthening programs by the private sector and the federal government, including the military, to assess and reduce earthquake risk to specific sectors crucial to the U.S. economy.

- In 2005, with financial and technical support from the World Bank, the government of Romania initiated a multisectoral earthquake risk management program. The program took a comprehensive approach to earthquake risk management through a forty-four-building pilot project addressing both structural and functional retrofitting and improving regulatory measures to mitigate future risk to buildings.

- In 2002, with financial and technical assistance from the World Bank, the government of Turkey developed the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). This ongoing, large-scale program has achieved total financing of over US$1.5 billion to date and has successfully retrofitted over 800 priority public buildings for seismic risk mitigation,

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3) From the MMEIRS M7.2 scenario earthquake along the West Valley Fault.
4) Generally, experience shows that five to seven schools can be strengthened and renovated for the cost of one new building.
improved the legal and regulatory framework and building codes, and strengthened emergency management capacity and awareness.

- In 2011, with funding from the World Bank, Indonesia—a country that faces natural hazards similar to those in the Philippines—successfully implemented a local-level pilot project in the education sector. The Safe School Pilot Project was a low-cost, five-month initiative covering a total of 180 schools in three provinces. It introduced retrofitting techniques focused on low-cost materials, such as chicken wire mesh, as well as nonstructural measures, such as evacuation simulations and education about disasters.

This report is divided into three sections. First, it establishes the technical principles of earthquake risk management. Second, it details the experience of the Philippines to date in developing an integrated earthquake risk management program, focusing on the methodology and results of a vulnerability assessment and prioritization conducted under the Safe and Resilient Infrastructure Program. Last, it reviews international experience with earthquake risk management programs of various scales and scopes, through the cases of California, Romania, Turkey, and Indonesia.

The key messages of the report are as follows:

- An integrated approach to earthquake risk management can strengthen key buildings and infrastructure and reduce the damaging effects of future disasters in the Philippines.
- Earthquake risk management and strengthening programs initiated by both the public and private sectors in many countries often consist of three phases: risk audit, risk assessment, and implementation.
- Several key technical components must be considered in the design of a phased earthquake risk management program, including a prioritization methodology.
Collapsed school in Manila. Photo by Gabriel Mistral/Getty Images
The Philippines is among the top disaster hotspots of the world. It is highly exposed to a wide range of natural hazards, which is a limiting factor in its sustainable development. It ranks eighth among countries most exposed to multiple hazards and thirteenth among those at high economic risk from natural disasters, with at least 85 percent of gross domestic product (GDP) generated in areas at risk (World Bank 2005). Located in the Pacific Ring of Fire, it is highly exposed to earthquakes, volcanic eruptions, and other geological hazards, as well as to many typhoons and frequent monsoon rains.

Over the past five years, the Philippines has experienced severe weather events resulting in considerable damage and losses. Typhoons Ondoy, Pepeng, Sendong, and Pablo claimed over 3,000 lives, affected more than 10 million people, caused economic damage and losses amounting to approximately US$5.7 billion, and affected new areas such as Mindanao that historically had not been hit by strong typhoons.

Typhoon Yolanda, which struck in November 2013, is considered among the strongest ever to make landfall, with over 6,200 fatalities and over 1,700 people missing. An initial estimate (GoP 2013) puts the total damage and loss from Yolanda at PhP571.1 billion (equivalent to US$12.8 billion). The total fiscal costs include those of a comprehensive program providing humanitarian relief, reconstruction, and rehabilitation of public infrastructure, social safety net programs, and targeted interventions for the poor and most vulnerable.

Catastrophe risk modeling for the Philippines (AIR/ADPC 2014) shows the country is expected to incur, on a long-term average basis, PhP206 billion (US$4.6 billion) per year in damage to public and private assets due to earthquake ground shaking, wind and precipitation induced by tropical cyclones, and precipitation induced by nontropical cyclones (monsoons). This analysis takes into account a 10,000-year catalogue of possible events to provide a more robust quantification of disaster risks than one based on short-term historical records. In the next twenty-five years, the Philippines has a 40 percent chance of experiencing a loss of more than PhP840 billion (US$18.8 billion) and casualties greater than 70,000 people, and a 10 percent chance of experiencing a loss of more than PhP2 trillion (US$44.8 billion) and casualties greater than 95,000 people.

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5 The “Ring of Fire” is a string of volcanoes and sites of seismic activity, or earthquakes, around the edges of the Pacific Ocean; see http://education.nationalgeographic.com/education/encyclopedia/ring-fire/?ar_a=1.
6 BangkoSentral exchange rate of US1 = PhP44.637, as of February 25, 2014.
7 Ibid.
These risks are driven, in large part, by unplanned or poorly planned urbanization and the resulting concentration of assets and people in hazardous areas. Urbanization is expected to reach over 60 percent of the population in the near future. The increase in people, compounded by inadequate construction quality of the built environment, places these urban areas particularly at risk for catastrophic economic and human losses.

The policy framework for disaster risk reduction is reflected in the Philippine Disaster Risk Reduction and Management (DRRM) Act (Republic Act No. 10121) of 2010, which emphasizes ex-ante actions—that is, preparedness, prevention, and mitigation—over emergency relief and response. The strategies for implementing the law are contained in the National DRRM Framework and Plan (2011–28), which identifies the high-priority areas of engagement for the sectoral agencies of the government.

The Metro Manila Earthquake Impact Reduction Study (MMEIRS),8 implemented from 2002 to 2004 by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), the Japan International Cooperation Agency (JICA), and the Metropolitan Manila Development Authority (MMDA), was a major initiative to improve the structural resilience of public assets and infrastructure in Metro Manila. MMEIRS evaluated seismic hazards and potential damage to and vulnerability of the area under various scenario earthquakes and developed a master plan for earthquake risk management. From the 105 priority actions identified in the master plan, 40 were selected as high-priority actions. These included (1) securing the emergency road network and (2) strengthening buildings against earthquakes. Following the release of the MMEIRS report, the Department of Public Works and Highways (DPWH) embarked on an ongoing program of retrofitting bridges in Metro Manila. In terms of risk reduction in the building stock, however, implementation was more limited.

Prompted by the success and cost effectiveness of large-scale investments in other countries in retrofitting public buildings as a means to reduce risk, DPWH initiated a technical assistance program with the World Bank to assess the vulnerability of Metro Manila schools. A key component of the initiative was the development of a prioritization methodology for the upgrading and retrofitting of critical assets. The results of the prioritization show that strengthening the most vulnerable 5 percent of school buildings (186) can reduce the number of student fatalities9 by 25 percent (more than 6,000 lives saved). By strengthening the most vulnerable 40 percent of school buildings (1,466), potential student fatalities can be reduced by 80 percent (more than 19,000 lives saved). In other words, upgrading a relatively small number of systematically selected structures can save a disproportionately large number of lives, and it would be more cost effective than building new schools.10

On October 1–2, 2013, in partnership with the World Bank, DPWH hosted the Forum on Safe and Resilient Infrastructure (World Bank 2013a). The forum provided a venue for the GoP to set a policy and initial strategy for a cross-sectoral program to build the resilience of critical public infrastructure and facilities (in particular, schools). The participants included various stakeholders from relevant national government agencies, local government associations, development partners, the disaster risk management community, and the private sector. Moreover, the forum showcased experiences from a number of regions and countries (including Colombia, Indonesia, Japan, Romania, Turkey, and the United States) that have implemented similar risk reduction programs, from which lessons and best practices can be distilled and applied in the Philippines.

9 From the MMEIRS M7.2 scenario earthquake along the West Valley Fault.
10 Generally, experience shows that five to seven schools can be strengthened and renovated for the cost of one new building.
Such international experience can provide useful insights for decision makers in the Philippines to address key questions, challenges, and prioritization needs. It demonstrates that many countries, both developed and developing, are making countrywide earthquake risk management investments, initiating the enabling legislative actions to support multihazard resilience in design and construction (beyond revisions to building codes), and applying lessons learned from the impacts of previous disasters to reduce the vulnerability of communities, facilities, and infrastructure.

As a result of the forum, DPWH committed to implementing the cornerstone phase of the Safe and Resilient Infrastructure Program in Metro Manila. This would involve upgrading approximately 200 of the most vulnerable public school buildings there, with a view to eventually scaling up to other sectors (for example, lifeline infrastructure) and geographical locations and to institutionalizing quality assurance systems.
Approximate epicenters of the recorded earthquakes in the Philippines since 1990

Strongest earthquake 1976
Moro Gulf earthquake

Deadliest earthquake 1976
Moro Gulf earthquake

Principles of Earthquake Risk Management

The Philippines has a well-documented and long history of destructive earthquakes, among other natural hazards. Recent earthquakes there have revealed that many public buildings and much infrastructure, including bridges, roads, and ports, are vulnerable to major damage and collapse, with the potential to cause heavy fatalities as well as economic losses. Many relatively new commercial buildings are also vulnerable; in the 1990 Luzon earthquake, newly constructed multi-story hotels collapsed, resulting in approximately 1,700 fatalities (Figure 1). More recently, the Cebu International Convention Center (built in 2006) suffered heavy damage during the magnitude (M)7.2 Bohol earthquake of October 2013; as of August 2014, it was still not operational.

Catastrophe risk modeling for the Philippines shows earthquake losses are higher than those from tropical cyclones for larger mean return periods of losses (greater than twenty-five to thirty years). Conversely, tropical cyclone losses are greater at smaller mean return periods of losses. This is primarily because tropical cyclones occur more frequently than earthquakes in the Philippines, but strong earthquakes typically cause higher losses than large tropical cyclones.

Throughout the world, public buildings such as schools, hospitals, and critical government buildings have proved to be among the most vulnerable classes of structures. Schools are especially vulnerable, given structural characteristics that typically include large rooms, large windows (particularly in tropical climates), and corridors, all of which lead to lower stiffness that results in large lateral displacements of the structure during a major earthquake. In the aftermath of disasters, hospitals, as well as transportation, power, water systems, and telecommunications network infrastructure, are functionally critical; swift resumption of public services and hospital operations helps to normalize the situation in affected areas and mitigate a secondary wave of human and economic losses. Since direct damage to critical infrastructure and associated interruptions in services can account for more than 50 percent of the overall financial losses from a major earthquake in an urban area (Yanev 2013a), earthquake risk management programs should prioritize assessment and retrofitting of these structures.

Over the years, countries facing severe natural hazards have moved beyond piecemeal revisions of building codes to initiating legislative and regulatory actions toward integrated, countrywide

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11 The “return period of losses” is an estimate of the likelihood of occurrence of a particular level of economic loss (not of the event that causes the losses). A larger return period indicates less frequent, but a higher level of, losses.
approaches to earthquake risk management. For instance, the state of California in the United States has continuously upgraded building codes over the past several decades to reflect lessons learned from the types of damage caused by earthquakes. It has also mandated and financed the strengthening of key public buildings and infrastructure, as well as private structures that are particularly at risk, and is currently taking the same approach with the remaining private sector facilities. As a result of its integrated earthquake risk management strategy, California has been able to reduce the risk to both public and private sectors dramatically, as have several countries with similar comprehensive approaches.

Such an approach to earthquake risk management can likewise strengthen key buildings and infrastructure and reduce the damaging effects of future disasters in the Philippines. An integrated earthquake risk management program would be a vital component of a comprehensive disaster risk management agenda for building the Philippines’s resilience—physical, financial, economic, and social—to multiple hazards.

**Technical Bases of an Earthquake Risk Management Program**

Strengthening existing public buildings and infrastructure can significantly reduce human and economic losses in countries that are highly exposed to earthquakes. Recent earthquakes in the Philippines demonstrated that the building stock and critical infrastructure, as well as nonstructural items and equipment, are highly susceptible to damage. This vulnerability can result in significant injuries and disruptions to operations and services, as building codes in the Philippines—as in many countries—do not provide seismic performance standards for these elements.

Well-developed capabilities in the Philippines, including a strong professional community, available risk analysis and engineering technology, and lessons learned from international experience, can equip the GoP to improve the assessment and mitigation of structural risk. Lessons learned and challenges revealed by the experience of other countries in implementing large-scale earthquake risk management programs can also help the Philippines implement a more cost-effective and time-efficient program.

Several key technical components must be considered in the design of a phased earthquake risk management program:

- High-resolution hazard mapping, to ensure areas are zoned correctly and at a scale useful for planning investments
- Inclusion in the national structural code of standards for retrofitting existing buildings
- Enforcement of building codes and improved construction quality
- Prioritization of structures for upgrading and retrofitting

**Earthquake and Multihazard Mapping**

Earthquake hazard refers to the estimated probability of exceeding a certain amount of ground shaking, or ground motion, in a specified amount of time (typically, fifty years). The hazard depends on the likely magnitudes and locations of earthquakes, how often they occur, and the properties of the rocks and sediments through which the seismic waves travel.

In many areas of the Philippines, earthquake hazard is underestimated and inadequately reflected in building code requirements. Earthquake hazard maps show the distribution of shaking levels with given probabilities of their occurring in specific geographical areas. These maps provide information
that assists engineers in designing infrastructure, buildings, and utilities that will withstand earthquake ground motions and are used in creating and updating building and structural codes, land use planning, and insurance pricing. Since seismic hazard has, in the past, been quantified at relatively low resolution, many buildings in the Philippines are designed to meet standards corresponding to earthquake ground shaking of lower intensity than what the area may actually experience. Areas that have historically experienced a large number of earthquakes, in particular, tend to have underestimated seismic design requirements because the impacts of the most severe events that are possible in such areas of high seismicity have usually not been observed in the relatively short period on record.

The development of high-resolution maps for other hazards, for investment planning, and for resilient structural design also needs to be fast tracked in the Philippines. Much of the damage to buildings, roads, bridges, and ports in the 1990 Luzon earthquake, for example, was due to foundation failures from liquefaction. This could have been mitigated through engineering design measures, had high-resolution liquefaction hazard maps been available. Super Typhoon Yolanda highlighted the urgency as well of better understanding and mapping storm surge at a high resolution to inform land use planning and reconstruction.

**Building Codes and Enforcement**

Existing buildings can be strengthened according to specific requirements developed either as part of the national structural code or as separate guidelines. In the Philippines, particularly in Metro Manila, hundreds of tall, multistory buildings have been designed for earthquakes following the same standards as those for small, low-rise buildings. The building codes generally do not account for the fact that some of these structures have thousands of occupants; apart from some stricter provisions for complex high rises, most do not have enhanced structural design requirements.

**Retrofitting guidelines in Turkey.** In contrast, Turkey (whose earthquake risk management program is discussed in detail in the international experience section, below) has developed comprehensive structural engineering strengthening and implementation guidelines for public buildings, with emphasis on schools and hospitals, under the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). The Turkish retrofitting guidelines were developed separately from the Turkish building code, primarily because the code then current did not have any such provisions for existing buildings. Though based on the provisions of the Turkish building code with input from U.S. guidelines (ASCE 41-06), the retrofitting guidelines are less stringent—that is, a certain level of damage is deemed acceptable—to make strengthening possible and cost effective (as compared to rebuilding) for as many structures as possible. In addition, the building code itself was completely revised and updated in 2007 to incorporate aspects of performance-based engineering design.

In the Turkish retrofitting guidelines, the engineer for a specific building or groups of buildings is charged with condition assessment, followed by analysis and determination of deficiencies. The guidelines present both conventional and state-of-the-art strengthening measures as options and discuss them in detail. For the assessment, trained structural engineers first identify suspected building inadequacies using construction documents, analysis and evaluation tools, and site visits. When the retrofitting guidelines were developed under ISMEP, most of the over 600 existing public

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12 Liquefaction is a phenomenon in which a saturated soil loses strength and stiffness in response to an applied stress, such as earthquake ground shaking. Drastic and irregular settlement of a building on liquefied soil causes structural damage, or it may render the building unserviceable even if no structural damage occurs.
buildings evaluated had no documentation (such as as-built drawings). Therefore, to assess the earthquake performance of existing buildings and develop the guidelines, teams of engineers undertook in-situ tests, site surveys and walk-throughs, soil investigations, and material testing to gather information about structural system geometry, component cross-sections, characteristics of materials, and soil conditions. The assessment found most of the existing structures lacking in adequate lateral load resisting systems and all lacking in ductility, and almost all structures built before 2000 in need of structural strengthening.

The key provisions of the retrofitting guidelines are the following:

- **Condition assessment**: Data are gathered in sufficient and reasonable detail to identify structural and nonstructural components that are essential for optimizing earthquake resistance.
- **Structural earthquake deficiencies**: Common structural deficiencies, such as irregular configuration, nonductile reinforcement detailing,13 unreinforced masonry infill walls, and so on are identified.
- **Earthquake hazard (strength of the earthquake motion)**: The level of seismic design is expressed in terms of design response spectra or suites of acceleration histories. The hazard due to earthquake shaking is defined on either a probabilistic or deterministic basis.
- **Analytical procedures**: The use of accepted analytical procedures, ranging from simplified static to nonlinear dynamic analyses, is allowed based on the building properties, configuration, and proposed strengthening scheme.
- **Structural performance levels**: Various performance levels are defined, and the level of damage for each level is described. The appropriate performance level for a given earthquake intensity is identified.
- **Strengthening**: Both conventional and innovative techniques are described, and their proper use and application are elaborated.

The retrofitting guidelines and the 2007 Turkish building code introduced three structural performance levels—Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP)—relating to damage states for elements of lateral force–resisting systems (see Figure 1.2). Existing public buildings were retrofitted to meet both LS and IO occupancy requirements (see Table 1.1.1).

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13 Nonductile structures lack the detailing necessary to prevent brittle failures and collapse. They are vulnerable to earthquake damage, and many have collapsed in recent earthquakes.
The IO performance objective implies a level of structural design that will result in limited damage, given a particular level of ground shaking; the basic vertical and lateral force–resisting systems of the building retain nearly all their pre-earthquake strength and stiffness. The LS performance level implies significant damage to the structure is expected to occur, given a particular level of ground shaking, but some margin against either partial or total structural collapse remains. The CP performance level implies the post-earthquake damage state of the building is on the verge of partial or total collapse.

The “earthquake probability of exceedance” (percentage), shown in table 1.1, is the likelihood that a particular level of ground shaking will occur over the time period being considered (in this case, any fifty consecutive years). A 2 percent probability of exceedance means there is a 98 percent chance the shaking will not exceed the value; hence, a 50 percent probability of exceedance denotes an event that is far more likely to occur in any given fifty-year period. In the case of weaker ground shaking associated with a 50 percent probability of exceedance, buildings may be expected to perform better than they do in events with lower probability (but stronger shaking). Table 1.1 shows that under ISMEP, the performance objectives of the retrofitting were such that, for most buildings, no damage would be expected for ground shaking with 50 percent probability of exceedance. Retrofitting standards for “intensively but short-term occupied buildings” were slightly less stringent, allowing for limited damage but ensuring immediate occupancy after the earthquake. At 10 percent probability of exceedance, the retrofitting objectives were such that “buildings to be utilized immediately after the earthquake,” “intensively and long-term occupied buildings and museums,” and “buildings containing hazardous materials” were strengthened to an IO level, while the remaining two occupancy types were retrofitted to a Life Safety level (mitigating against partial or total structural collapse). In the case of extremely strong but rarer ground shaking levels (2 percent probability of exceedance), “buildings to be utilized immediately after the earthquake” and “intensively and long-term occupied buildings and museums” are expected to be designed and constructed to the Life Safety level, while “buildings containing hazardous materials” fall under the less stringent performance level of Collapse Prevention.

### Table 1.1 Building Performance Objectives

<table>
<thead>
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<th>Purpose of occupancy</th>
<th>Earthquake probability of exceedance in 50 years</th>
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<td></td>
<td>50%</td>
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<tr>
<td>Building to be utilized immediately after the earthquake</td>
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</tr>
<tr>
<td>Intensively and long-term occupied buildings and museums</td>
<td>–</td>
</tr>
<tr>
<td>Intensively but short-term occupied buildings</td>
<td>IO</td>
</tr>
<tr>
<td>Building containing hazardous materials</td>
<td>–</td>
</tr>
<tr>
<td>Other buildings</td>
<td>–</td>
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**Retrofitting guidelines in the Philippines.** In the Philippines, a set of technical guidelines similar to those in Turkey has been developed under the Safe and Resilient Infrastructure Program to address the seismic design requirements for upgrading existing public schools and hospitals in Metro Manila. The guidelines reflect state-of-the-art earthquake retrofitting procedures tailored to local construction practices. While the Philippines has long had a legal technical seismic design code for the design of new buildings—the National Structural Code of the Philippines (NSCP), which was most recently updated in March 2010 (ASEP 2010)—it has had no such code for upgrading existing buildings. The new technical guidelines are intended as a supplement to the NSCP to address the
retrofitting of existing buildings, and they can assist engineers in future earthquake strengthening projects.

In the guidelines, the Life Safety (LS) structural performance level is used for evaluating existing buildings. This performance level is equivalent to that specified in the provisions of the NSCP. Seismic performance of a building depends on the characteristics of the earthquake event. A sample structure might perform well when it is subjected to one class of earthquake but experience substantial damage when subjected to another. Determining the seismic hazard before attempting assessment or retrofitting is, therefore, imperative. The seismic hazard is based on the provisions of the NSCP and depends as well on the soil conditions at the site and the proximity of the building to the earthquake source.

Since seismic performance also greatly depends on a building's design and construction, specifying the requirements for detailed site investigations to quantify the critical existing building parameters is important. A review of school and hospital construction drawings has shown a large majority of the school buildings and many hospitals use reinforced concrete construction. The typical lateral load–resisting system consists of reinforced concrete moment-resisting frames. In many of these buildings, hollow concrete block infill panels are used.

Although the most recent version of the NSCP generally follows the principles and design requirements of modern seismic design, most reinforced concrete buildings constructed in accordance with the provisions of earlier editions of the national structural code are considered nonductile or of limited ductility. Nonductile structures lack the detailing necessary to prevent brittle failures and collapse. Nonductile reinforced concrete structures are vulnerable to earthquake damage, and many have collapsed in recent earthquakes. For this type of construction, the most economical and structurally viable strengthening option is to apply conventional retrofitting techniques, such as adding new elements (for example, reinforced concrete shear walls) to carry the full seismic load. With this approach, no strengthening of the existing elements is required. The guidelines present sample designs and detailing for such retrofits.

The vulnerability assessment and retrofitting methods provided in the guidelines rely on the existing worldwide knowledge base and are further refined to address the specific conditions of the subject buildings in Metro Manila. A great majority of the buildings use reinforced concrete framing with hollow concrete block infill. They are often large, high-occupancy facilities, and their collapse in future earthquakes could result in hundreds or thousands of casualties. Therefore, retrofitting of these buildings is considered a high priority and is emphasized in the guidelines.

The guidelines provide strengthening methods that will significantly improve the seismic performance of school and hospital buildings in Metro Manila. To remain cost effective, a certain level of building damage is considered acceptable, but people will be safer and more confident that building collapse will be mitigated. The overall objectives are to achieve acceptable earthquake performance, minimize the cost of retrofitting, and maximize the number of buildings rehabilitated. School and hospital buildings strengthened in accordance with the guidelines are expected to meet their performance targets when they are subjected to the design earthquake for Metro Manila, as specified in the NSCP.

14 The ground movement that is used in the calculation of the earthquake resistant design.
Cost effectiveness and enforcement of new structural design requirements. Stricter structural design requirements constitute a small portion of the overall construction cost of new buildings and are a cost-effective investment against future earthquakes. A high level of earthquake-resistant design and construction that preserves the structural and nonstructural elements from major damage has been found to increase the overall cost of the building by 2–4 percent. This incremental cost increase is due to the use of additional materials, such as extra reinforcing steel and concrete, for a more robust structural frame, which brings the cost of the structural system up by approximately 20 percent. The structural system itself is a small portion of the overall cost of a completed building—usually 10–20 percent for more complex and larger buildings—while the rest is in the architectural features and exterior finishes, furnishings, and equipment systems.

Better enforcement of structural codes is crucial to reducing structural damage and financial and human losses, particularly in earthquake-prone areas. A field assessment by the Association of Structural Engineers of the Philippines after the M7.2 Bohol earthquake of 2013 showed much of the damage was due to inadequate structural detailing and substandard material quality. Successful implementation of an earthquake risk management program in the Philippines will be contingent upon the strict enforcement of structural code requirements, through both the engineering design and construction processes.

Several countries have successfully strengthened code enforcement, particularly concerning public buildings and infrastructure, by training and licensing professional engineers and exerting tighter control over engineering and construction quality. Turkey, for example, recently established detailed course requirements for obtaining engineering licenses in response to the widespread structural damage caused by the 1999 earthquakes; many, if not all, of the newer buildings that collapsed simply did not meet the earthquake requirements of the building codes. Both the engineering designs and construction were inadequate since no system was in place in much of the affected area to check whether the designs met the code requirements for earthquake resistance or the construction was of adequate quality. A further serious problem in Turkey was the absence of professional registration for structural engineers; anyone who graduated with a degree in civil engineering from the country’s universities could immediately sign design drawings. The licensing requirements have thus provided a quality control mechanism for engineering design.

In California, graduate engineers are required to obtain licenses, which involves testing on the subject of earthquake-resistant design, before they can sign structural drawings. Young engineers typically practice design under the direction of licensed and experienced engineers for several years before they take their professional examinations. The licensing process is supported by the profession and enforced by the state of California, with detailed courses taught to accelerate learning. Such courses can easily be set up through either professional societies or universities across the Philippines, similar to what is done in Turkey.

Prioritization of Public Buildings and Infrastructure

From an architectural and engineering perspective, schools are among the most structurally vulnerable types of buildings. They tend to have large rooms and windows and fewer interior walls than other structures of similar size and capacity, such as apartment buildings, which have relatively small rooms encircled by many more walls. As a result, schools are among the first buildings to collapse in earthquakes, while others built to similar design standards remain standing. To make matters worse, schools are frequently used as community refuges and emergency shelters, as was the case in the aftermath of Super Typhoon Yolanda in the Philippines, the Great East Japan Earthquake,
and Hurricane Katrina in the United States. Fortunately, their architectural and structural simplicity makes strengthening school buildings cost effective and relatively easy.

Similarly, hospitals are among the most easily damaged public and private buildings. Along with other medical buildings, they generally have larger rooms, fewer walls, and specialized equipment and supplies that can be costly to replace. They are, moreover, more difficult to evacuate than other types of buildings; moving seriously ill patients can be detrimental and sometimes fatal to them. Hospitals must also be able to resume operations quickly after an earthquake. Without functioning hospitals, the recovery of communities from a disaster can be significantly hampered.

Government buildings, such as city halls, emergency response centers, police stations, and fire stations, are critical for emergency response and rescue activities, yet they too are highly vulnerable to earthquakes. In the Philippines, as in much of the rest of the world, these facilities are typically designed to the same earthquake standards as conventional buildings, even though they need to remain operational during emergencies. Fire stations, in particular, have proved highly susceptible to earthquake damage because they have large openings in their ground-floor walls to accommodate the fire engines. It is important to note that government and municipal buildings are often more expensive than others to strengthen, as they are typically one-of-a-kind and larger—often historic—buildings.

Finally, transportation and other lifeline infrastructure frequently suffer major damage from earthquakes as a result of their geographical, structural, and functional features. Bridges suffer disproportionate damage compared to other types of transportation infrastructure because they are typically located in areas with poorer soils, such as along rivers, which tend to amplify ground motion. Airports also tend to be vulnerable due to their large size, architectural design, and dependence on equipment and utilities for service. Telecommunications networks, power generation and distribution systems, and water and wastewater systems are usually inadequately protected, despite the critical role functioning utilities services play in normalizing the situation in disaster-affected areas. Building codes around the world have little to no requirements for the protection of critical nonstructural equipment, such as underground pipes or the ceramic components of emergency power systems.

Many countries have successfully implemented country- and citywide earthquake risk management programs by prioritizing the upgrading and retrofitting of critical infrastructure (see Box 1.1). In these countries, regulations for schools, hospitals, emergency facilities, police and fire stations, and critical public buildings are in a constant state of improvement; building codes continue to evolve for new construction, while older buildings are strengthened to reduce the risk to levels comparable with that of new construction. In this process of updating building codes, drawing relevant lessons from the performance of structures in each new disaster is vital.
Box 1.1 Strengthening Schools, Hospitals, and Critical Infrastructure in California

Since the early 1900s, the state of California has been retrofitting critical types of structures to improve their earthquake resistance. The 1906 San Francisco earthquake provided the first major impetus for the development of seismic design codes and safety standards. Subsequent earthquakes in 1925, 1933, 1971, 1989, and 1994 prompted responses through continuous improvement of codes and implementation of retrofitting programs based on an increasingly greater understanding of seismic design. In the 1930s, public school buildings became one of the first classes of structures to be retrofitted and more strictly regulated. Starting in the 1970s, stringent regulatory requirements were expanded to include hospital buildings and critical public infrastructure, such as dams and bridges.

California’s effort to reduce earthquake risk in critical buildings is an ongoing process that has spanned decades and cost several billion dollars. Earthquake design regulations are in a constant state of improvement, as engineers learn new and applicable lessons from earthquakes around the world.

Source: Yanev 2013a.

Developing an Earthquake Risk Management Program

Integrated earthquake risk management programs are typically multiphased, long-term initiatives. They involve the analysis of earthquake risk to a particular set of assets or infrastructure, followed by risk reduction programs that can take from a few years to decades to complete. Successful earthquake risk management and strengthening programs initiated by both the public and private sectors in many countries have often consisted of three phases—risk audit, risk assessment, and implementation—elaborated as follows:

- **Phase 1—Risk audit of a specific sector:** A sector-specific risk audit (for example, pertaining to public school buildings in the education sector or hospitals in the health sector) should be a quick study based on engineering judgment and minimal engineering analyses.

- **Phase 2—Detailed risk assessment:** Phase 2 includes cost-benefit analysis for the particular sector and prioritization of assets.

- **Phase 3—Implementation:** Phase 3 involves reducing risks through strengthening and retrofitting of the prioritized assets, nonstructural components, and equipment systems. The implementation phase mostly consists of construction, accompanied by the establishment of systems for quality assurance.

**Phase 1: Risk Audit**

The risk audit determines the general severity of the problem at hand for the pre-identified sector. Take, for instance, the education sector in the Philippines: how much damage would occur to schools in a given city, such as Metro Manila, in a strong earthquake whose expected magnitude and strength of shaking is based on a realistic assessment of the local seismicity and geology? Which schools, specifically, would be damaged, and what would be the extent of the damage and the likely casualties?

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15 For more information, see section “International Experience in Earthquake Risk Management,” below.
For many sectors, the risk audit is a relatively simple analysis, conducted in a matter of few weeks to months at a low cost. Many school buildings in the Philippines, for example, particularly the older ones, lack any significant seismic design features and are therefore expected to suffer extensive damage. The risk audit carried out in Metro Manila had to estimate the extent of the potential damage and rate the schools so the most vulnerable and damage-prone buildings would be strengthened first, or possibly rebuilt entirely. This risk audit was conducted in 2011 under the GoP’s long-term engagement with the World Bank, in support of the country’s overall disaster risk management agenda.

In such an audit, risks are identified by applying standard screening methods and engineering expertise locally. The screening and analyses are also based on damage information collected for the types of structures of interest from recent earthquakes worldwide. The building structures are then rated in order of priority for strengthening. The relevant line ministry or sectoral agency is typically involved throughout the risk audit process, as it is crucial for them, first, to share ownership of and responsibility for the earthquake risk management program and, second, to integrate risk reduction and management measures into the sector’s overall budgeting and planning. In addition, sectoral agencies typically have detailed information on their assets (for example, location and age of buildings) and on challenges that may arise, enabling them to arrive at politically acceptable and cost-effective solutions reasonably quickly.

**Phase 2: Detailed Risk Assessment and Cost-Benefit Analysis**

Once a risk audit has been completed, the detailed risk assessment and cost-benefit analysis phase is conducted to develop preliminary recommendations for strengthening the prioritized buildings. Vulnerability and economic analyses evaluate the costs and benefits (usually derived from avoided losses) associated with structural upgrades. This is the type of assessment that was conducted in Metro Manila under the Safe and Resilient Infrastructure Program, which resulted in prioritization of the 200 most vulnerable school buildings. A unique aspect of this vulnerability analysis was the use of avoided life losses rather than avoided physical damages or economic losses as the measure of benefit. Thus, the vulnerability assessment and cost-benefit analyses for Metro Manila schools determined the “number of student lives saved” as the specific criterion for prioritizing the strengthening of existing school buildings.

The first task in a seismic vulnerability assessment of a portfolio of assets is to develop a suitable set of earthquake performance goals for the structures. The American Society of Civil Engineers Seismic Evaluation of Existing Buildings ASCE/SEI 31-03 recommends two basic levels of performance—Life Safety (LS) and Immediate Occupancy (IO)—based on the level of post-earthquake service that needs to be provided (ASCE 2003). At the LS performance level, risk of life loss or serious injury to the building occupants during the design earthquake is reduced. Damage is allowed to both structural and nonstructural components of the buildings only to the extent that a partial or total structural collapse does not occur during the design earthquake and that damage to nonstructural components is not life threatening. The IO performance level is more stringent and is used for essential facilities that need to be operational and without loss of life after the design earthquake event. These usually include operation control buildings, hospitals, emergency response centers, police and communication centers, and facilities containing large amounts of hazardous substances.

In the technical guidelines developed under the Safe and Resilient Infrastructure Program, the LS performance level is used as the retrofitting objective for existing buildings. The LS level is equivalent to the provisions of the NSCP (for the design of new buildings) and was selected to align with the
overall objectives to minimize the cost of retrofitting, achieve acceptable earthquake performance, and maximize the number of buildings that can be rehabilitated. Using the IO level as the objective, which would allow for only very limited structural damage in a given earthquake scenario, would make the program extremely costly. Although greater amounts of damage that do not threaten injury are considered acceptable at the LS level this performance goal is sufficient to safeguard lives and mitigate building collapse for more schools within the same overall program budget.

In short, the purpose of any detailed risk assessment and cost benefit analysis is to optimize the number of structures that can be strengthened under the expected program budget while meeting the selected criterion for the performance of the buildings (for example, performance level or lost business days or service interruptions resulting from an earthquake). Large programs in which many similar buildings are strengthened have a big cost advantage over smaller ones due to economies of scale; during the implementation of such programs, project engineers are often able to optimize the cost for a large number of buildings, based on their growing experience in program implementation (see Box 1.2).

### Box 1.2 Turkey: Cost Savings through Implementation of a Large-Scale Program

The Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP) is multifaceted, but its primary component is the strengthening and reconstruction of priority public buildings, particularly schools. The government established the Istanbul Project Coordination Unit (IPCU) to manage ISMEP with assistance from international experts who had varied experience in setting up large seismic retrofitting programs.

To date, ISMEP has completed the strengthening, reconstruction, and renovation of over 800 schools, hospitals, and other buildings that were found to have high earthquake risks. By the end of the current phase of ISMEP in 2014, more than 1,100 such buildings will have been strengthened and/or rebuilt. Tight control of funds throughout the implementation phase, along with the size of the program, has resulted in large cost savings through economies of scale. Throughout the project, the various international consultants engaged in it worked with the ISMEP staff and all of its Turkish engineers and contractors to transfer technology and experience from other large retrofitting programs. Capacity building of the ISMEP staff and local project engineers occurred naturally during both the design and the construction processes.

*Source: Alaluf 2013a, 2013b.*

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15 Constructing a new school building would cost approximately US$580 (PHP25,000) per square meter, while upgrading an existing school building, including earthquake strengthening and functional upgrades (for example, to bathrooms), would cost approximately US$120–260 (PHP5,200–11,000) per square meter, depending on the number of stories and the site requirements. Comparing the two costs shows the cost of upgrading is about 20–40 percent that of new construction. Based on the 20 percent estimation, Metro Manila can strengthen and renovate nearly five school buildings for the cost of one new one. Cost analyses were based on a survey of several Metro Manila contractors.
Phase 3: Implementation

The third and final phase of an earthquake risk management program, and generally the costliest and longest, is its implementation. Construction costs comprise around 90 percent of the total cost, while the remaining 10 percent consists of costs relating to engineering, program administration, and field inspections. The total cost of the program will depend on the final engineering design of the strengthened buildings, the complexity of their contents and equipment, and the actual construction costs.

For this phase to be successful, carrying it out requires qualified project engineers with extensive experience designing and implementing seismic retrofitting and strengthening projects. The added participation in an advisory capacity of engineers with international experience can facilitate technology and knowledge transfer, which is particularly important with regard to construction management and enforcement of standards, as these can greatly affect the quality of implementation of large-scale retrofitting projects (see Box 1.3).

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**Box 1.3** Current Challenges in Construction Management in the Philippines

Engineering design and construction management in the Philippines are based directly on U.S. codes, standards, and practices. Both private engineering firms and government engineering offices have been affected, however, by a significant exodus of experienced professionals to other countries in response to the global demand for engineers and technical staff. As a result, the engineering and construction management industries, particularly in the public sector, are often affected by the following issues:

- **Lack of training in construction supervision.** A significant number of personnel in the provincial engineering offices lack experience or are not properly trained for construction management work. In some cases, lack of continuing education results in the use of obsolete guidelines and practices that are no longer applicable for today’s standards.

- **Lack of technical training in structural engineering.** Particularly in less urbanized areas, simple infrastructure projects such as low-story buildings, roads, and drainage are designed by provincial engineering offices, which frequently lack seismic design experience.

- **Poor quality control and documentation.** The integrity and quality of construction depend on quality tests being conducted and appropriate documentation being kept. Oftentimes, projects are not executed according to the technical specifications provided in the structural designs. Moreover, as-built construction drawings sometimes are not properly filed, affecting future upgrading and retrofitting work.

- **Poor planning, scheduling, and cost estimation.** Many engineers at the provincial level have inadequate training or background in planning and implementing projects. The consequent changes to the project implementation schedule can drive up the costs. Building this capacity for large seismic retrofitting projects, which cover the strengthening of hundreds to thousands of buildings, is essential.

Earthquake scenario studies can provide policymakers with a direct and to-the-point understanding of the potential losses in a given geographical area. Initial studies may be simple deterministic scenarios developed in a few months at a moderate cost. The resulting approximations provide policymakers with a tangible evidence base for political and financial decision making. Public and private sector entities regularly conduct such scenario analyses to assess the financial, physical, and human losses that could result from a disaster. Electric power utility companies, for example, use them to understand how their facilities and business services would be affected in a given disaster event, and municipal engineers and scientists use them to estimate the expected effects of major earthquakes in given geographical regions. Oftentimes, earthquake scenario studies precede earthquake risk reduction and management programs, as they reveal the extent to which major losses and business interruptions could be incurred in the absence of such programs. For instance, the University of California’s Berkeley campus initiated an earthquake strengthening program after completing a comprehensive earthquake scenario analysis that rated all campus buildings in order of overall risk, based on criteria such as number of occupants, building function, and financial impact from loss or damage to the building (see box 2.1).

In 2004, a multiyear earthquake risk assessment called the Metro Manila Earthquake Impact Reduction Study (MMEIRS) estimated the potential physical and human losses and impacts of different earthquake scenarios in Metro Manila. The assessment evaluated the vulnerability of residential, commercial, and public buildings and lifeline infrastructure (such as bridges and water systems); economic and political impacts; and emergency response capacity. The MMEIRS identified 105 priority action plans, of which 40 were selected as high priority. Included among the 40 key recommendations were (1) to strengthen buildings against earthquakes and (2) to enhance the emergency health and medical response system.

The recommendations for earthquake risk management in the 2004 MMEIRS were broad and high-level, but the report was short on details on how to prioritize the strengthening of buildings and lacked concrete operational guidelines for developing an earthquake risk mitigation program. Following its release, the DPWH embarked on an ongoing program of retrofitting bridges in Metro Manila, but implementation of a risk reduction program for the building stock was more limited in the ensuing ten years.

The Forum on Safe and Resilient Infrastructure provided a broad platform to present the findings of the technical assistance, which aimed to create a methodology for assessing in detail the

Integrated Earthquake Risk Management in the Philippines
Box 2.1 Earthquake Risk Management Program for the University of California, Berkeley Campus

With its population of about 30,000 students and its large faculty, administration, and support community, the University of California’s Berkeley campus is equivalent in many ways to a small city. Built on hilly terrain, the campus contains particularly complex systems for running its varied operations and straddles one of California’s main earthquake faults—the Hayward Fault (a branch of the larger and famous San Andreas Fault), which is similar to Metro Manila’s West Valley Fault in that it transects the city.

The UC Berkeley campus, which dates back to the early 1870s, thus faces one of the highest earthquake risks in the world. The fault can generate an earthquake with a magnitude in the low to mid-sevens. The probability of such an earthquake’s occurrence is believed to be one of the highest known through a major area—on the order of 1 to 2 percent per year, which is comparable to, for example, that for Istanbul, Turkey.

With state and federal funding, the campus and its earthquake risk have been transformed over the past thirty years. (The surrounding city of Berkeley, with a population of about 110,000, has also implemented a wide-ranging earthquake risk reduction program that, in itself, would be an excellent “best practices” example, but it will not be discussed here.) Structural strengthening of some of the oldest and most dangerous buildings on campus (constructed with unreinforced masonry) began in 1978. In 1997, the university created the Seismic Action Plan for Facilities Enhancement and Renewal (SAFER) as a comprehensive, long-term framework for devoting more resources to strengthening or replacing vulnerable buildings.

By 2006, half of the total floor space identified in SAFER as needing retrofitting had been strengthened to various performance standards, depending on occupancy and other factors. By 2011, about 75 percent of the work had been completed. Most existing buildings were strengthened, some of the older ones at great expense because the work could not easily be done without affecting their historical architectural features. Many buildings built in the 1960s and ’70s were also strengthened, illustrating the progress made in earthquake engineering over the past several decades. Retrofitting of numerous multistory dormitory buildings found to be dangerous substantially reduced potential future losses of life.

The retrofits include a variety of state-of-the-art techniques for providing additional protection to existing buildings of many types. Some buildings were torn down and replaced. The campus became a laboratory for the implementation of the latest techniques for strengthening buildings. The work continues and, hopefully, will be completed before the next major earthquake occurs on the Hayward Fault.

Source: Yanev 2013a.
vulnerability of school buildings to multiple hazards, prioritize them for upgrading, and provide technical guidance on structural strengthening and upgrading. It also provided tailored design examples for upgrading typical school buildings in Metro Manila. The DPWH also discussed an initial strategy for the implementation phase of the cross-sectoral Safe and Resilient Infrastructure Program with development partners and various stakeholders in relevant national government agencies, local government associations, the disaster risk management community, and the private sector.

**Multihazard Prioritization for Public Buildings**

Public schools and hospitals in Metro Manila have different levels of vulnerability to earthquakes, floods, typhoons, tsunamis, and volcanic eruptions. One task carried out for the detailed vulnerability assessment was development of a prioritization methodology to help identify the highest risk candidate structures for upgrading and risk reduction. Below is a summary of the key natural hazards that affect Metro Manila and their resulting impacts.

**Typhoon and Flood**

The Philippines and its surrounding seas are affected by an annual average of nineteen tropical cyclones, or typhoons (Aquino 2005), which bring strong winds, heavy rainfall, storm surges, floods, landslides, and mudslides. In recent years, Metro Manila has been directly affected by severe winds, most notably Typhoon Milenyo (international name, Xangsane) in September 2006; Typhoon Ondoy (international name, Ketsana) in September 2009; and a heavy southwest monsoon rain event (locally known in Filipino as “Habagat”) in August 2012. The last of these was associated with Typhoon Haikui, which passed through north of Taiwan.

In Metro Manila, Typhoon Milenyo was said to have reached a recorded maximum sustained wind speed of 35 meters per second and a gust speed of 45 meters per second (Pacheco et al. 2006). These were below the basic gust wind speed (that is, the fifty-year return period) of 55 meters per second for Metro Manila, as prescribed by the 2010 National Structural Code, which makes the Milenyo wind speeds in Metro Manila equivalent to approximately a twenty-year return period wind speed, according to the procedure in the ASCE/SEI 7 commentary for hurricane-level winds (ASCE 2010). The amount of damage, death, and injury caused by the winds of Typhoon Milenyo was among the worst in more than a decade, particularly for Metro Manila, which had approximately US$24 million in damage and about 200 deaths.

Typhoon Ondoy brought the highest rainfall and flooding in the history of Metro Manila, causing floodwaters to rise to a height of more than two meters in the span of just a few hours in some locations. Ondoy was actually just a tropical storm (maximum sustained wind and gust speeds of no greater than 28 meters per second and 31 meters per second, respectively) when it affected the Philippines; it became a typhoon only when it approached Vietnam. As a windstorm, Ondoy may be said to represent only a one- or two-year return period event for Metro Manila, but the return period for the rainfall it brought is estimated at a hundred to a hundred and fifty years (Liongson and Tabios 2009). A total of 465 deaths resulted from Ondoy.

The Habagat storm of 2012 brought perhaps the second-worst flooding since Typhoon Ondoy in 2009, but the rains spread over a few days instead of hours and caused landslides in one part of Metro Manila. In one area, the floodwaters reached a height of approximately 1.8 meters because of Ondoy, but only about 1.5 meters because of the Habagat storm. In other areas of Metro Manila, for both storm events, floodwaters rose to at least 3 meters. The maximum twenty-four-hour rainfall
brought by the Habagat was 472 millimeters—higher than the maximum twenty-four-hour total for Ondoy (455 millimeters). Considering the limitations of current rainfall modeling, the Habagat can be considered a rainfall event with a return period greater than one hundred and fifty years.

These storms caused flooding and wind damage to Metro Manila buildings. Based on interviews with Department of Education and hospital staff, the resulting deaths and injuries at schools and hospitals were minimal, even though schools are sometimes used as shelters in such events.

Typhoon Pablo (international name, Bopha) of 2012 made landfall on the southern island of Mindanao as a Category 5–equivalent super typhoon, with one-minute sustained wind speed of 280 kilometers per hour. It was one of the costliest reported typhoons ever to strike the Philippines, causing over US$600 million in damage and 1,020 deaths (NDRRMC 2012). The costliest was Super Typhoon Yolanda. It made landfall in the Visayas (Central Philippines) in November 2013 with Category 5–equivalent winds and storm surges of five to six meters. Considered to be the strongest typhoon ever to make landfall, Typhoon Yolanda resulted in approximately 8,000 dead and missing. The total damage and loss from typhoon Yolanda has been initially estimated at PhP571.1 billion (equivalent to US$12.9 billion).

Volcanic Activity

The Philippines is an archipelago of more than 7,100 islands, most of which are of volcanic origin. Of the thirty-seven volcanoes in the Philippines, eighteen are active. The rest are dormant and not expected to erupt in the near future. The best-known volcanoes are Mount Pinatubo (eighty kilometers northwest of Manila), Mount Banahaw (sixty kilometers southeast of Manila), and Taal (forty kilometers south of Manila); all are on the northern island of Luzon.

The last major eruption (the second largest of the twentieth century) was that of Mount Pinatubo in June 1991. Evacuation zones ten to forty kilometers from the volcano’s summit (affecting a population of about 40,000) were established before the eruption, thereby significantly reducing casualties. A reported 847 people were killed, mostly by roofs collapsing under the weight of accumulated wet ash, a hazard that was amplified by the simultaneous arrival of Typhoon Yunya. Some schools in the evacuation zone were damaged by the ash fall, thereby disrupting education (Martí and Ernst 2005). Metro Manila was well outside the forty-kilometer evacuation zone and reported only minor damage and injuries. The impact to Metro Manila schools and hospitals was similarly light.

Earthquakes and Tsunamis

Because the Philippines is located along the Ring of Fire (see above), it faces major risks from earthquakes and tsunamis. Significant earthquakes in 1976 (Mindanao, M7.9) and 1990 (Luzon, M7.7) killed up to 8,000 (Soloviev, Go, and Kim 1992) and 1,666 people (Rantucci 1994), respectively. West of Metro Manila is the Manila Trench, which can generate large subduction-type earthquakes that can cause destructive tsunamis. Major tsunamis, with waves one to one and a half meters in height, struck Metro Manila in 1677, 1744, 1824, 1852, and 1863 (Nakamura 1978).

The MMEIRS report (PHIVOLCS/JICA/MMDA 2004) estimated losses from a M7.2 scenario nighttime earthquake on the West Valley Fault at 168,300 heavily damaged buildings, 33,500 deaths, and 113,600 injured. Of schools and hospitals, 10 percent are expected to collapse or sustain significant damage, and 25 percent are expected to have moderate damage. Tsunami risk was analyzed by using Model 13, a M7.9 subduction faulting event on the Manila Trench. Under this scenario, tsunami waves of two to four meters are expected to reach Metro Manila in seventy minutes. The 2013 population
of Metro Manila was 12 million and the population of Greater Manila 25 million. Extrapolating the MMEIRS numbers results in approximately 83,750 deaths and 284,000 injured if that nighttime earthquake were to strike today. Numbers for a daytime earthquake on the West Valley Fault are expected to be much higher.

Both the 1976 Mindanao and 1990 Luzon earthquakes damaged schools, but because they struck in the evening when school was not in session, they caused few student deaths. Similarly, the M7.2 Bohol earthquake in 2013 struck during a school holiday and, as a result, no students died. The MMEIRS estimates, as mentioned, are also based on an evening earthquake scenario, when schools are not in session. A daytime event would be catastrophic. Recent local education reforms to add the eleventh and twelfth grades to secondary schools will add 2 million students to existing school buildings in two years. This will dramatically increase the number of two-shift schools, which in turn will make a class-time earthquake the likely scenario.

Estimates of high casualties among students from a daytime earthquake are supported by data from the 2008 earthquake in Sichuan, China, which killed 19,000 (Swiss Re 2009), or a little over 1 percent of the student population (see figure 2.1). Metro Manila school buildings have earthquake vulnerabilities similar to those in China (for example, nonductile concrete construction, infilled masonry walls, and variable construction quality). In 2013, Metro Manila’s public school population was approximately 2.15 million students; a 1 percent fatality rate would equate to 21,500 student deaths at this population level. The number of injuries would be significantly higher. In 2017, following full implementation of the educational reforms, the number of students is expected to increase to 2.4 million. If school buildings are not strengthened by then, the number of children at risk of dying will increase to 24,000.

**Figure 2.1** Schools collapsed in the 2008 Sichuan, China, Earthquake (M8.0)

Source: Miyamoto 2008.

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**Multihazard Prioritization**

The U.S. Federal Emergency Management Agency (FEMA), Applied Technology Council (ATC), PHIVOLCS/MMDA/JICA (which conducted the MMEIRS study), and others typically use sophisticated computer models, such as Hazus, to estimate portfolio losses from different natural hazards. The results are used for policymaking, disaster response planning, and other planning exercises. For the Safe and Resilient Infrastructure Program, a simplified prioritization methodology was developed to demonstrate the disaster impacts at a qualitative level, with the goal of showing that, if buildings
are not strengthened against earthquakes, associated life losses will be orders of magnitude greater than those from other natural disasters. A first-order analysis of the natural hazards and potential consequences for schools and hospitals in particular, based on a review of Philippine natural hazard loss history, highlighted the significantly greater threat that is presented to them by earthquakes, as compared to other natural hazards.

**Typhoons and floods.** Since the Philippines is struck by major floods and typhoons frequently, its people are prepared for and its buildings generally resistant to major damage from these events; most damage is nonstructural (for example, strong winds can cause damage to a building’s roof but are unlikely to cause collapse). Most schools and hospitals are constructed of reinforced concrete—one of the construction types most resistant to typhoons and floods—so structural damage in these events is rare. Also, the warning system in the country for both typhoons and floods is sophisticated, so citizens can prepare for them and/or evacuate to avoid them. For major typhoons, schools are typically closed but are sometimes used as shelters. Typhoon and flood casualties in, and property damage to, Metro Manila public schools and hospitals have historically been low.

**Volcanic eruptions.** The three known “active” volcanoes, Taal, Mount Banahaw, and Mount Pinatubo, are too far away from Metro Manila to cause lahar damage (that is, damage from landslide or mudflow, the greatest hazard from volcanoes) to the area. They also are not expected to deposit enough ash on public school or hospital buildings to cause structural damage or failure. Although risk of property damage and injury is high next to an erupting volcano, Metro Manila schools and hospitals are far enough away that they are expected to below.

**Tsunamis.** Earthquake-induced tsunamis from the west have an impact on coastal areas. As mentioned above, tsunami waves following a major earthquake on the Manila Trench are expected to take about seventy minutes to reach Metro Manila, which gives people in low coastal areas some time to evacuate or move to upper floors of multistory concrete buildings. As seen in Japan from tsunami induced by the M9.0 earthquake in 2011, property damage can be significant. In the Japanese event, however, reinforced concrete buildings performed much better than other building types when struck by tsunami waves (see Figure 2.2). For the approximately 30 percent of Metro Manila schools and hospitals located in the western part along low-lying coastal areas, moderate damage is expected. Casualties are expected to be low, provided sufficient warning is given for evacuations.
Earthquakes. Earthquakes present the greatest risk of death to occupants of Metro Manila schools and hospitals. The M7.2 West Valley Fault (WVF) scenario earthquake in the MMEIRS has a return period of 200 to 400 years, and the last earthquake on WVF was over 300 years ago (Daligdig et al. 1997; PHIVOLCS/JICA/MMDA 2004). This means the WVF M7.2 earthquake can strike at any time. In addition to putting people in danger, this impending hazard affects building stock that is particularly vulnerable to earthquakes. Metro Manila school and hospital construction is mostly reinforced concrete frame, and many of these structures are of the nonductile variety, which has been associated with the highest death rates in past earthquakes (see Figure 2.3, green squares).

Figure 2.3 Casualties Associated with Reinforced Concrete Structures in Earthquakes

A WVF M7.2 daytime event associated with 20,000 deaths, annualized at 0.01 (that is, with a 1 percent chance per year of occurring), would result in a long-term average of 200 deaths per year for Metro Manila schools and hospitals—an order of magnitude greater than those resulting from flood, hurricane, and volcanic events (typically a long-term average of less than 10 per year).

**Prioritization and Cost-Benefit Analysis of Earthquake Strengthening**

The main objective of prioritizing the more than 3,000 distinct school buildings (on more than 700 school campuses) in Metro Manila was to identify whether a subset of these buildings needed to be retrofitted and, if so, determine what criteria could be used to prioritize investments and quantify the range of costs and associated benefits of an earthquake strengthening program. The status quo—no strengthening—was used as the baseline.

**Prioritization**

The prioritization and selection for earthquake upgrade of the buildings at highest risk were based on building vulnerability and expected casualties derived from the M7.2 West Valley Fault MMEIRS scenario and drew from the methodology of earthquake risk management programs in other countries, such as the World Bank–supported ISMEP in Turkey. Because most of the school buildings in Metro Manila are of similar construction type (reinforced concrete frame with masonry infill walls), the vulnerability ranking is directly correlated with the resulting fatalities from structural damage and collapse.

Vulnerability and fatality calculations were based on the probabilistic methods developed in ATC-13 (ATC 1985) and FEMA Hazus (FEMA 2001) and were used to rank the buildings under investigation. To estimate vulnerability and fatalities for a particular building, four distinct parameters were used as input: seismic hazard, exposure, building vulnerability, and fatality index.

For this prioritization, a database of buildings was developed incorporating these parameters. The following is a summary of the definitions and procedures used to determine these variables.

**Seismic hazard.** The seismic hazard used in the analysis was based on the design response spectrum as defined in the National Structural Code of the Philippines. This spectrum is similar to the “Scenario 8” (M7.2, West Valley Fault) event that was examined previously by the MMEIRS project and designated as the critical event for investigation.

Development of the elastic response spectrum was based on the procedure outlined in the NSCP and included such factors as the seismic zonation (zone 4 for Metro Manila), the classification of subgrade soil at the site, and the shortest distance from the building site to the fault.

Data for the type of soil (typically, class D or E) at various school campuses were determined from the available PHIVOLCS liquefaction maps. Hence, the prioritization methodology takes liquefaction potential into account.

Geographical coordinates (latitude and longitude) were provided in the database of school buildings that was furnished by the Department of Education (DepEd). Because the geometric coordinates of the West Valley Fault are known, the perpendicular distance to the fault line was calculated for each school campus. With this value, the near-field effects for various campuses could be computed.
The design spectrum for an individual building was then developed based on the procedure listed in the NSCP, modified for the site class and near-field effects. The resulting site-specific spectrum comprised the seismic hazard for each building.

**Exposure.** The exposure for each building was based on its student population (used to estimate fatalities), floor area (in square meters), and construction characteristics (used to estimate potential structural damage). To estimate the exposure for each building, the DepEd database was modified to address the following:

- The existing DepEd database was incomplete (the population and building data for a number of buildings were missing).
- More recent DepEd estimates indicate the student population is larger than the values shown in the database.
- An independent survey of 130 random buildings conducted on twenty-two campuses showed the existing database underestimated the number of stories and the floor areas of the surveyed buildings.

The database entries were thus modified as follows:

- Because the populations of individual buildings within a given school campus were unknown, the campus population was distributed to the buildings in proportion to the floor area of each.
- When the year of construction of a given building was unknown, it was assumed to have been constructed after 1990 but before 2001 and in compliance with the edition of the National Structural Code adopted in that period.
- The number of students in each building was multiplied by the ratio of the most recent estimate of the total student body in Metro Manila divided by the total student population indicated in the database.
- The number of stories of individual buildings was multiplied by the ratio of the observed number of stories for the 130 surveyed buildings divided by the total number of stories indicated in the database for those 130 buildings.
- The floor area of buildings was multiplied by the ratio of the actual total floor area for the 130 buildings surveyed divided by the total floor area indicated in the database for those 130 buildings.

The revised database was then used for synthesis. It should be noted that more complete facility information is needed to define better the top candidate (highest risk) buildings for earthquake strengthening and upgrading. Over 25 percent of the data fields (that is, a quarter of the information) used for this analysis were blank or unknown, and the remaining data often did not match the information gathered during the field surveys. There were also no data on the number of students per school building, just a total for each campus.

**Building vulnerability.** Structural vulnerability for the analysis was based on fragility data from Hazus, which shows the probability of exceeding a damage state as a function of the building drift ratio. In other words, the parameters (means and variances of the lognormal curves) for the fragility functions (that is, damageability) of a given building, at a particular intensity of ground shaking, were based on the following factors:

- Construction material (for example, reinforced concrete)
- Lateral load–resisting system (for example, moment frame)
Number of stories
Construction date and design data (used to determine code compliance)
Construction practices

In this simulation, the default parameters from FEMA Hazus were used and the following was noted:

- The buildings were almost exclusively constructed of reinforced concrete.
- Moment frames were the primary lateral force-resisting system for the buildings.
- In terms of FEMA Hazus classifications, the buildings were either low-rise (one to three stories) or mid-rise (four to seven stories).
- The buildings were constructed according to the version of the NSCP adopted at the time of their design and construction. Three separate vintages were identified: post-2001, 1991–2001, and pre-1991. The post-2001 NSCP was based on the 1997 Uniform Building Code (UBC), and earlier versions were likewise based on previous editions of the UBC.
- Onsite surveys during construction showed the construction quality control was inadequate, and construction practices did not closely follow the design plans and specifications. Therefore, the code compliance for each design vintage was downgraded by one level for the analysis.

Thus, using the FEMA Hazus methodology, the Metro Manila buildings were assigned the seismic design levels listed in Table 2.1.

Table 2.1 Hazus Building Seismic Design Level Classifications

<table>
<thead>
<tr>
<th>Construction data</th>
<th>FEMA Hazus code compliance assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-2001</td>
<td>Moderate code</td>
</tr>
<tr>
<td>1991–2001</td>
<td>Low code</td>
</tr>
<tr>
<td>Pre-1991</td>
<td>Pre-code</td>
</tr>
</tbody>
</table>

Source: Miyamoto 2014.

The analysis also used four damage states defined by FEMA Hazus, typically with corresponding fragility functions (see Figure 2.4). Their definitions for a reinforced concrete moment-frame building (referenced as C1 below) are as follows:

- **Slight structural damage:** Some beams and columns have flexural or shear-type hairline cracks in, near, or within joints.
- **Moderate structural damage:** Most beams and columns exhibit hairline cracks. In ductile frames, some of the frame elements have reached yield capacity, indicated by larger flexural cracks and some concrete spalling. Nonductile frames may exhibit larger shear cracks and spalling.
- **Extensive structural damage:** Some frame elements have reached their ultimate capacity, indicated by large flexural cracks, spalled concrete, and buckled main reinforcement. Nonductile frame elements may have suffered shear failures or bond failures at reinforcement splices or broken ties or buckled main reinforcement in columns, which may result in partial collapse.
- **Complete structural damage:** Structure has collapsed or is in imminent danger of doing so because of brittle failure of nonductile frame elements or loss of frame stability.
Fatality index. The Hazus indoor fatality rates (FEMA 2001, chapter 13) for concrete moment-frame low-rise (C1L) and concrete moment-frame mid-rise (C1M) buildings are summarized in Table 2.2.

Table 2.2 Hazus Indoor Fatality Rates for Concrete-Frame Buildings

<table>
<thead>
<tr>
<th>Building type</th>
<th>Fatality rate, no collapse</th>
<th>Fatality rate, collapse</th>
<th>Collapse rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1L</td>
<td>0.01%</td>
<td>10%</td>
<td>13%</td>
</tr>
<tr>
<td>C1M</td>
<td>0.01%</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Source: Miyamoto 2014.

Hazus building-collapse rates for "complete structural damage" are 13 percent for C1L and 10 percent for C1M. Collapse rates for unreinforced masonry are 15 percent for URML (low-rise) and for URMM (medium-rise). Hazus fatality rates are uniform across all building types, so fatality estimates must factor in the collapse rates. Based on this logic, fatality rates for reinforced concrete buildings should be slightly lower than for unreinforced masonry buildings. MMEIRS findings on the relationship between fatalities and building damage are quite different from Hazus findings, however (PHIVOLCS/ JICA/MMDA 2004). The MMEIRS findings show fatality numbers in reinforced concrete buildings are actually between 5 and 100 times (an average of 20 times) those in unreinforced masonry buildings, consistent with post-earthquake observations in Sichuan, China (2008, M8.0),
and Haiti (2010, M7.0). Therefore, the fatality numbers were adjusted for the analysis by a factor of 6 and the collapse rate by a factor of 2.5. The adjusted rates for C1L and C1M buildings used in the ranking algorithm are summarized in Table 2.3.

For each level of damage defined earlier, a percentage of the population was assigned as the fatality rate. For each building, the probable fatality ratio was then considered by aggregating the probability of exceeding a damage state and the fatality rate associated with that damage state. It should be noted that only indoor fatalities were used in this study. Fatalities outside of buildings due to falling hazards were not included, but they can add 5–10 percent to the indoor fatality rates.

Table 2.3 Adjusted Hazus Indoor Casualty Rates for Metro Manila Concrete-Frame Buildings

<table>
<thead>
<tr>
<th>Building type</th>
<th>Fatality rate, no collapse</th>
<th>Fatality rate, collapse</th>
<th>Collapse rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1L</td>
<td>0.06%</td>
<td>60%</td>
<td>33%</td>
</tr>
<tr>
<td>C1M</td>
<td>0.06%</td>
<td>60%</td>
<td>25%</td>
</tr>
</tbody>
</table>

Source: Miyamoto 2014.

The following is a summary of the key steps for determining the top candidates for earthquake strengthening, based on the prioritization process discussed above:

- For each building, compile the following information:
  - Building identifier
  - Building coordinates
  - Seismicity
  - Occupants and area
  - Fragility parameters (mean and standard deviation) for each damage state
- Compute probabilistic values for damage states by using the fragility functions corresponding to the building construction type, lateral load framing system, number of stories, and vintage.
- Compute fatality ratios by using the fatality rate for each damage state and the probability of exceeding that damage state.
- Compute earthquake strengthening costs by using the cost estimate per square meter and building floor area.
- For Metro Manila schools, use a total student population of 2.15 million.
The earthquake hazard assessment and building upgrade prioritization process is summarized in Figure 2.5.

**Seismic hazard**
- Fault characteristics
- Soil characteristics
- Fault distance
- Attenuation relation (MMEIRS scenario 8)

**Facility input data**
- From DepEd and DOH

**Augmented facility data**
- **Building data:** Construction type, year built, number of stories, foundation system, and roof type.
- **Occupancy data:** Number of occupants by building

**Hazus-type program**

**Hazarus adjustments**
- Poor earthquake design
- Poor construction
- Concrete collapse ratio
- Death ratio

**Aggregate fatalities**

**Fatality determination**
- By building

**Building risk ranking**
- Based on fatalities per building

**Earthquake upgrade prioritization**

*Figure 2.5 Earthquake Upgrade Prioritization Process*

*Source: Miyamoto 2014.*
Analysis Results

The prioritization process revealed that public school buildings in Metro Manila are at high earthquake risk. For a M7.2 earthquake scenario as simulated in the 2004 MMEIRS, approximately 50 percent of the 3,821 public school buildings evaluated from available databases were found to be high-risk structures that will incur significant damage or collapse. Student fatalities in a daytime earthquake were estimated at 24,400 out of 2.15 million students in Metro Manila, based on 2013 figures (Miyamoto 2013; see figure 2.6).

**Figure 2.6** Student Fatality Distribution in Metro Manila Public Schools, M7.2 West Valley Fault Daytime Earthquake

*Source: Miyamoto 2014.*
Based on the ranking of these buildings according to risk levels, the risk assessment distilled the following results (see Figure 2.7):

- 18 percent of all fatalities will occur in less than 3 percent of the assessed school buildings.
- 25 percent of all fatalities will occur in less than 5 percent of the assessed school buildings.
- 80 percent of all fatalities will occur in less than 40 percent of the assessed school buildings.

A short-term goal may be to upgrade 100 to 200 of the buildings at highest risk immediately. Doing so will reduce the death toll by 25 percent, or 6,385 students. School upgrades will enhance safety and improve the functionality of older and higher-risk structures. Seismically upgraded school structures will also provide more resilient disaster shelters for typhoons and floods.

**Cost-Benefit Analysis**

The cost-benefit analysis revealed that up to five existing school buildings can be strengthened and renovated for the cost of one new one. Public schools and hospitals in Metro Manila are generally multistory, reinforced concrete constructions. They have insufficient detailing based on older seismic design codes. School strengthening would therefore enhance the safety and improve the functionality of older and higher-risk structures. Moreover, seismically upgraded school structures would serve as more resilient disaster shelters for typhoons and floods.

Based on analysis of both conventional retrofitting techniques (that is, adding shear walls or braced frames; improving the existing component detailing) and innovative methods (such as seismic isolation...
and energy dissipation), a school building in Metro Manila could be upgraded for approximately 20–40 percent of the total cost of constructing a new or replacement school.\(^\text{17}\) Upgrading the most vulnerable 5 percent of school buildings would cost approximately US$40 million–80 million and save nearly 6,400 student lives, and upgrading the most vulnerable 40 percent would cost approximately US$178 million–356 million and save over 19,000 student lives (see Table 2.4).

**Table 2.4** Cost-Benefit Analysis for Upgrading and Strengthening Metro Manila School Buildings

<table>
<thead>
<tr>
<th>Number of buildings (out of 3,821 total)</th>
<th>Costs</th>
<th>Student lives saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>186 most vulnerable buildings (5%)</td>
<td>US$40 million–80 million (PhP1.7–3.5 billion)</td>
<td>6,390 (25% of predicted casualties)</td>
</tr>
<tr>
<td>1,466 most vulnerable buildings (40%)</td>
<td>US$178 million–356 million (PhP7.7 billion–15.3 billion)</td>
<td>19,330 (80% of predicted casualties)</td>
</tr>
</tbody>
</table>

Source: Miyamoto 2013.

Data on hazards and building exposure were collected for the risk assessment from various government agencies, while an initial pool of buildings was documented through site visits, visual surveys, and photos. The documentation was reviewed, assessed, and categorized and aggregated with available facility data collected from the government agencies, including the National Disaster Risk Reduction and Management Council, the Department of Education, the Department of Health, the Philippine Atmospheric, Geophysical, and Astronomical Services Administration, and the Philippine Institute of Volcanology and Seismology. To develop a ranking for each building, internationally accepted methods of risk assessment algorithms were used to correlate the earthquake hazards with probable human loss metrics.

Prioritization of buildings in risk assessment studies is essential to ensure the optimal allocation of available funds during the implementation phase of an earthquake risk management program. Using the prioritization methodology described above, each of the 3,821 school buildings in Metro Manila was ranked, factoring in such key parameters as construction type and vulnerability, construction date (age of the building), number of stories, number of occupants, and site geology.

Also relevant to the budget of an earthquake risk management program are institutional, political, and regulatory considerations. For example, to calculate cost parameters as accurately as possible, a program that retrofits school buildings in the Philippines would necessarily incorporate the priorities, budget, data, and other resources of the relevant line agency or department. An implementation strategy might be designed according to the following steps and could be accomplished within an overall time frame of three to four years:

1. To optimize the selection of buildings under consideration, coordinate with the Department of Education and the Philippine Institute of Volcanology and Seismology to collect the most

\(^{17}\) Constructing a new school building would cost approximately US$580 (PHP25,000) per square meter, while upgrading an existing school building, including earthquake strengthening and functional upgrades (for example, to bathrooms), would cost approximately US$120–260 (PHP5,200–11,000) per square meter, depending on the number of stories and the site requirements. Comparing the two costs shows the cost of upgrading is about 20–40 percent that of new construction. Based on the 20 percent estimation, Metro Manila can strengthen and renovate nearly five school buildings for the cost of one new one. Cost analyses were based on a survey of several Metro Manila contractors.
Applications of International Experience

up-to-date building data (two months). Engage universities, technical agencies, and practicing engineers for basic data collection. A cornerstone retrofitting program could target, for instance, a selection consisting of the 100 to 200 most structurally vulnerable school buildings.

2. Concurrently, establish a separate project management office to manage the cornerstone retrofitting program (two months). The office would handle the procurement and contracting process for structural analysis, design, and construction (two months).

3. In parallel, establish an expert panel to develop and conduct a short course (four months) to train Philippine structural engineers on the use of the earthquake strengthening guidelines to upgrade high-risk schools. The panel could be composed of representatives from DPWH, the University of the Philippines, the Association of Structural Engineers of the Philippines, and other technical organizations.

4. Establish a quality control system (two months) for engineering design (for example, to review designs and check plans) and construction (for example, to test materials and inspect construction) to ensure high-quality and well-built schools.

5. Perform detailed seismic analysis of the highest risk buildings to identify vulnerabilities, determine upgrading needs, and develop construction cost estimates (six months).

6. Develop construction plans (twelve months).

7. Construct the earthquake upgrades (eighteen months).

Upon completion, such a program will have reduced the potential student fatality rate in a major earthquake by approximately 20–25 percent, based on the M7.2 MMEIRS earthquake scenario, and strengthened disaster shelters for the safety of communities in future typhoons and floods. The program could then be scaled up and implemented nationwide.

Guidelines for Earthquake Strengthening of Public Schools and Hospitals in Metro Manila

The guidelines for earthquake strengthening of schools and hospitals in Metro Manila were developed with technical assistance from the World Bank under its Safe and Resilient Infrastructure Program to help address the seismic upgrade requirements for public buildings in Metro Manila. The guidelines are recommended for use as a supplement to the 2010 edition of the National Structural Code of the Philippines (NSCP), which is the legal technical seismic design code in the Philippines for the design of new buildings. The NSCP was updated in March 2010, and its seismic requirements closely follow the provisions of the 1997 Uniform Building Code (ICBO 1997).

Although the most recent version of the NSCP generally follows the principles and design requirements of modern seismic design, most of the reinforced concrete buildings that were constructed in accordance with the provisions of earlier editions are considered nonductile or of limited ductility. As mentioned earlier, nonductile structures lack the detailing necessary to prevent brittle failures and collapse. Nonductile reinforced concrete structures are vulnerable to earthquake damage, and many have collapsed in recent earthquakes.

For this type of construction, the most economical and structurally viable strengthening option is the application of conventional retrofitting techniques, such as the addition of new elements (for example, reinforced concrete shear walls) to carry the full seismic load. Using this approach, no strengthening of the existing elements would be required. The guidelines present example designs and detailing for such retrofits.
The risk assessment and retrofitting methods used in the guidelines rely on the existing worldwide knowledge base and are further refined to address the specific conditions of the subject buildings in Metro Manila. A great majority of the buildings use reinforced concrete framing with hollow concrete block infill. These types of buildings are often large, high-occupancy facilities, and their collapse in future earthquakes could result in hundreds or thousands of casualties. Therefore, retrofitting of these buildings is considered a high priority and is emphasized in the guidelines.

The strengthening methods provided in the guidelines will significantly improve the seismic performance of school and hospital buildings in Metro Manila. To remain cost effective, a certain level of building damage is considered acceptable, but greater life safety will be ensured, and people will be more confident that building collapse will be mitigated. School and hospital buildings strengthened in accordance with the guidelines can be expected to meet their performance targets when they are subjected to the design earthquake for Metro Manila.

The guidelines are divided into three volumes (see Figure 2.8):

- Volume I provides a prescriptive methodology for evaluating and upgrading school and hospital buildings.
- Volume II provides detailed background information and advanced analysis and evaluation techniques, including the use of performance-based engineering.
- Volume III provides design examples for use in evaluating typical Metro Manila school and hospital buildings. The examples illustrate the upgrade methods prescribed in volume I.

For a great majority of the buildings, the provisions of volume I and the design examples and detailing provided in volume III most likely will be used. Volume II is intended to be used for unique structures or when alternative approaches are required—for example, for buildings with irregularities for which the linear static procedure is not allowed, or when alternative or innovative upgrade options that are not covered in volume I have been selected.

Many technical sections of the guidelines are based on the provisions of FEMA 356 (NEHRP 2000). As reinforced concrete frame construction is prevalent in Metro Manila for most school buildings and many hospitals, the guidelines focus on that type of construction.

The procedure specified in the guidelines for assessing and upgrading a given building is as follows:

- Determine the seismic hazard for the building per the National Structural Code of the Philippines.
- Perform a condition assessment.
- Perform linear static analysis.
- Assess the performance of the building.
- For inadequate buildings, design upgrade options as defined in volume I, based on the procedures of the NSCP, to carry 100 percent of the lateral load and limit story drift ratios to 1 percent. Provide detailing as presented in volume III.
- Check nonstructural component anchorage and nonbuilding structures, such as water towers.
Figure 2.8 Flowchart for Application of the Guidelines (Chapter Citations Refer to Volume I)
Source: Miyamato 2014.
Burbank, California, US Secretary of the Interior Dirk Kempthorne (C) and United States Geological Service (USGS) Seismologist Lucy Jones (L) participate in a region-wide simulation of an expected catastrophic 7.8 magnitude earthquake on the San Andreas Fault during the Great Southern California ShakeOut earthquake drill. Photo: David McNew/Thinkstock.com
International Experience in Earthquake Risk Management

International experience can provide insight into the potential challenges and key lessons of developing and implementing earthquake risk management programs. The Forum on Safe and Resilient Infrastructure held on October 1–2, 2013, provided an opportunity for the government of the Philippines to exchange knowledge with several countries that had implemented their own seismic retrofitting and upgrading programs. As the GoP formulates the implementation strategy of its earthquake risk management program, the following examples of different structural resilience programs worldwide (including large-scale, pilot, countrywide, and region-wide) can inform the scope and design of the implementation strategy in the Philippines.

California: Multidimensional Earthquake Risk Management

Since the early 1900s, the state of California has been retrofitting critical classes of structures to strengthen them and mitigate the impacts of disasters. The 1906 San Francisco earthquake was the first major impetus for the development of building design codes and safety standard regulations. The reactive measures, driven by a greater understanding of risk following each major earthquake, has led to a large-scale, ongoing earthquake risk management program that encompasses structural retrofitting, regulatory codes, and legal enactments to address the risk to critical buildings and infrastructure.

Schools

The 1933 Long Beach earthquake (M6.4) destroyed most of the schools in the city of Long Beach, despite their having been mostly new buildings designed to the earthquake standards then current. Seventy schools were destroyed, 120 suffered major damage, and 300 received minor damage. The event catalyzed enactment one month after the earthquake of the Field Act, mandating special earthquake designs for schools. The act, which established the Office of the State Architect (now the Division of the State Architect, or DSA) to regulate the design and construction of all public school buildings throughout the state, includes the following provisions:

- School building construction plans must be prepared by qualified California-licensed structural engineers and architects.

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18 Unless otherwise specified, the information in this section is from Yanev 2013a.
19 For more information, see http://www.seismic.ca.gov/pub/CSSC_2004-04_School%20Safety.pdf.
20 For more information, see http://www.dgs.ca.gov/dsa/home.aspx.
Designs and plans must be checked by DSA for compliance with the act before a contract for construction can be awarded.

Qualified inspectors, independent of the contractors and hired by the school districts, must continuously inspect construction and verify full compliance with plans.

The responsible architects and/or structural engineers must observe the construction periodically and prepare changes to plans (if needed), subject to approval by DSA.

Architects, engineers, inspectors, and contractors must, under penalty of perjury, file reports to verify compliance of the construction with the approved plans, emphasizing the importance of testing and inspections to achieve seismically safe construction.

Based on state bureau regulations, review of the engineering design is conducted by independent third parties, and the construction process is supervised by state and private industry engineers. Private licensed and prequalified engineers do most of the plan checking and review for the state (or local) agency. The costs to DSA of plan checking and review are passed on to the owner through construction permit fees.

For many years, the regulatory requirements for schools in California significantly exceeded those for all other types of buildings. The schools have performed much better in strong earthquakes than any other type of building, and no public school building has collapsed in an earthquake in California since the passage of the Field Act.

**Hospitals**

The collapse of major hospital buildings during the 1971 San Fernando earthquake (M6.5) in the Los Angeles metropolitan area was the impetus for stronger regulations for hospital buildings. As a direct response to the disaster, which included damage to hospitals considered state-of-the-art at the time, California’s legislature passed in 1973 the Alfred E. Alquist Hospital Seismic Safety Act, which requires that hospitals be designed and constructed to withstand a major earthquake and remain operational immediately afterward (box 3.1). The Alquist Hospital Act established the Facilities Development Division (FDD) within the Office of Statewide Health Planning and Development to regulate the earthquake design and construction of hospitals.21 In the aftermath of the 1994 Northridge earthquake (M6.7), the act was expanded in scope to require that all hospitals survive earthquakes without collapsing or posing the threat of significant loss of life and that all critical equipment within hospitals remain functional.

**Critical Public Infrastructure**

Advances in strengthening public infrastructure followed a similar pattern to efforts to strengthen schools. The destructive effects of the San Fernando earthquake prompted major changes in the earthquake design, regulation, and construction of power transmission facilities and highway structures. The California Department of Transportation initiated a bridge seismic safety retrofitting program focused on strengthening existing highways and bridges, and the currently operating Caltrans Seismic Retrofit Programs were established following the unprecedented damage to transportation

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21 In a move that it executed in 1983 and further clarified in 1991, the California state legislature transferred all responsibility related to hospital construction plan review from local building departments to the newly created FDD. FDD became the single point of accountability and authority for design review and construction observation activities relating to hospitals. For more information, see http://www.oshpd.ca.gov/FDD/About_Us/History/.
Applications of International Experience

infrastructure throughout the San Francisco region caused by the 1989 Loma Prieta earthquake (M6.9). The Caltrans Seismic Retrofit Programs have been focused on identifying and retrofitting existing bridges statewide, bringing them up to the latest seismic safety retrofit standards to prevent collapse during future earthquakes.

The Northridge earthquake was another wakeup call, with costs exceeding US$50 billion in direct damage, several times greater than the cost of the Loma Prieta earthquake. The California legislature mandated further review and strengthening, as necessary, of all highways and other bridges in the state. The Division of Safety of Dams in the Department of Water Resources was strengthened as the enforcement agency charged with ensuring dam safety by reviewing designs and plans and conducting inspections of all new and existing dams in California. As a result, most dams have been strengthened or replaced entirely based on detailed risk assessments and cost-benefit analyses carried out over the last forty-two years.

California’s ongoing large-scale programs for reducing earthquake risk to schools, hospitals, other buildings, and public infrastructure have spanned decades and cost several billion dollars. The efforts of the state have led to greater public awareness, and the federal government, including the military, is undertaking similar programs to assess and reduce existing earthquake risk to specific sectors crucial to the U.S. economy. Driven by the realization that massive business interruptions and production losses caused by earthquakes could be dramatically reduced or eliminated, private companies in California have also been engaged in structural strengthening programs since the 1980s to evaluate and reduce the existing risks to their buildings, including building contents, production and service equipment, and inventory.

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**Box 3.1 Subsequent to the Alquist Hospital Seismic Safety Act of 1973**

The moderate (M6.7) Northridge earthquake in 1994 cost US$3 billion in hospital-related damage and evacuations. While hospitals built in accordance with the 1973 Alquist Hospital Act very successfully resisted structural damage, many older (pre-1973) hospital buildings performed poorly and sustained extensive nonstructural damage (for example, to plumbing and ceiling systems). As a result, the Alquist Hospital Act was amended by Senate Bill (SB) 1953, which was signed into law in September 1994. Under SB 1953, all hospitals are required to survive earthquakes without collapsing or posing a threat of significant loss of life. In addition, all existing hospitals are to be seismically evaluated and rated according to seismic resistance.

Although the law mandated replacement or retrofitting by 2013 of the buildings most at risk to meet seismic safety standards, the economic recession caused the California legislature to pass a law in 2009 delaying the deadlines until 2020 or 2030. For more information, see http://www.seismic.ca.gov/pub/CSSC_2001-04_Hospital.pdf and http://www.californiahealthline.org/think-tank/2010/california-hospital-seismic-safety-rules-center-stage-again.

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22 For more information, see http://www.dot.ca.gov/hq/paffairs/about/retrofit.htm.
23 For more information, see Caltrans Seismic Advisory Board (2003).
24 For more information, see http://www.water.ca.gov/damsafety/FAQAnswer/index.cfm.
Romania: Hazard Risk Mitigation and Emergency Preparedness Project

The 1977 Vrancea earthquake (M7.2) prompted the development of substantive building codes and a seismic risk management system in Romania. Most fatalities and property damage were concentrated in Bucharest, where most buildings had been built before World War II and were not structurally reinforced (See Figure 3.1). Overall, approximately 35,000 buildings were damaged, with total costs estimated at over US$2 billion. Immediately following the earthquake, the Romanian government imposed more stringent construction standards. Not until well into the 2000s, however, did it begin to address the country’s vulnerability to earthquake risk in a more comprehensive manner.

In 2005, the Romanian government requested World Bank financial and technical support to implement a comprehensive and multisectoral earthquake risk management program, consisting of both structural and institutional measures to reduce the vulnerability of high-priority technical and social infrastructure. The program identified key infrastructure and high-priority public buildings for structural retrofitting and, in parallel, developed institutional strengthening measures, such as building design codes, to increase the capacity of central and local institutions to perform their related functions. The multisectoral earthquake risk management program was developed and implemented as one component of the broader Hazard Risk Mitigation and Emergency Preparedness Project (HRMEP) to reduce the country’s overall financial, economic, social, and environmental vulnerability to natural disasters. The total cost of the program was approximately US$150 million.

Retrofitting Key Buildings

Under HRMEP, more than 300 key public buildings were identified, of which 84 were selected for retrofitting based on a prioritization methodology consisting of social, economical, technical, and functional criteria. During the implementation phase of the program, several key factors affected the overall procurement and contracting plan in terms of cost, complexity, and duration. First, the scope of retrofit upgrades was substantially expanded to ensure buildings would quickly recover full functionality following earthquakes (that is, Immediate Occupancy performance level). Second, with Romania’s accession to the European Union (EU), building designs had to be reviewed based on stricter technical requirements and quality regulations to comply with EU structural safety and functionality standards. The 2010 European economic crisis affected the state budget, and some buildings had to be dropped from the program due to funding constraints. As a result, the number of buildings was ultimately narrowed down to 44 (see table 3.1).

Table 3.1 Building Facilities Selected for Retrofitting under the Romania HRMEP

<table>
<thead>
<tr>
<th>Category of building facilities</th>
<th>Number of facilities out of 44 buildings total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency and disaster response facilities</td>
<td>17 (38%)</td>
</tr>
<tr>
<td>Hospitals (national and provincial level)</td>
<td>14 (32%)</td>
</tr>
<tr>
<td>Educational (universities, child protection centers)</td>
<td>10 (23%)</td>
</tr>
<tr>
<td>Essential public buildings</td>
<td>3 (7%)</td>
</tr>
</tbody>
</table>

Source: Petrescu 2013.

25 Unless otherwise specified, the information in this section is from Petrescu 2013.
26 For more information, see http://gemecd.org/event/170.
Finally, a risk assessment of electricity, gas, and oil facilities was developed to support potential future structural improvement projects for key lifeline infrastructure.

**Building Codes and Capacity Building**

In addition to physically strengthening key buildings, the HRMEP addressed the institutional and regulatory weaknesses that constrained development of a more resilient building stock. The retrofitting methodology implemented under the project was based on stricter provisions in a new building code, and innovative building designs used new, cost-effective techniques. To transfer knowledge and technology and build the capacity of Romanian earthquake engineers and structural specialists, an international engineering firm was engaged for project implementation and worked in partnership with Romanian engineers and designers. The international firm also developed a
comprehensive guidebook on innovative retrofitting methods and implemented a series of three professional training seminars with thirty to forty stakeholder participants.

While the Romanian experience was a small-scale, forty-four-building pilot, the lessons learned throughout its implementation phase can be informative for earthquake risk management programs in the Philippines and worldwide. For example, involving the engineering community in Romania throughout implementation in partnership with the international engineering firm was crucial.

Also instructive is the program’s comprehensive approach to earthquake risk management, which encompassed multiple sectors, addressed both structural and functional retrofitting, and improved regulatory measures to mitigate future risk to buildings.

Most significantly, the implementation models developed through this pilot program can be scaled up in similar projects for other sectors or cities.

**Turkey: Istanbul Seismic Risk Mitigation and Emergency Preparedness Project**

Over 80 percent of Turkey’s population lives in areas exposed to earthquake risk. These areas also generate more than 80 percent of the country’s gross national product (GNP). The 1999 Marmara earthquake (M7.4), the most destructive in recent years, resulted in 17,500 fatalities, nearly 675,000 people displaced, and 113,000 collapsed and 264,000 damaged buildings. Fiscal costs were in the range of US$2.4 billion–2.9 billion. The largest direct cost (estimated at US$1.6 billion) was attributed to the reconstruction and repair of housing stock, much of which was owned by middle- and high-income residents (World Bank 1999).

Many, if not all, of the newer buildings that collapsed did not meet the earthquake requirements of the building codes that were in force in 1999. The earthquake brought to the government’s and the public’s attention the lack of building code enforcement, inadequate engineering designs, improper construction inspection, and governance issues related to obtaining building permits and licenses.

Following this experience, the government of Turkey developed a new disaster risk management model that shifted the priority from reaction and response to proactive risk reduction and mitigation. Under the integrated disaster risk management system, the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP) was developed to reduce the structural vulnerability of existing buildings and infrastructure in Istanbul. With financial and technical assistance from the World Bank, risk audits and preparation for implementation began in 2002.

With total financing of over US$1.5 billion to date, ISMEP is an ongoing, large-scale program consisting of three key components:

- Strengthening emergency management capacity and awareness
- Retrofitting priority public buildings (mainly schools and hospitals) for seismic risk mitigation
- Improving the legal and regulatory framework and building codes

To date, ISMEP has completed the strengthening, reconstruction, and renovation of over 800 schools, hospitals, and other critical public buildings prioritized for their vulnerability to earthquake risks. The program recently received much additional financing from several other sources to greatly expand its scope, and by the end of the current project phase in 2014 more than 1,100 such buildings will have been strengthened and/or rebuilt (Figure 3.2).

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27 Unless otherwise specified, the information in this section is from Elgin 2013.
Institutional Arrangement

To manage its flagship investment initiative efficiently, the government of Turkey established a separate government unit, the Istanbul Project Coordination Unit (IPCU), under the Istanbul Special Provincial Administration to supervise and manage the implementation of ISMEP. The IPCU is responsible for project coordination, procurement, financial management, contract management, monitoring, evaluation, and reporting. It is headed by a technically qualified project director who reports directly to the governor of Istanbul, and a senior staff member from each government agency (including health, education, and public works) functions as a liaison between the IPCU and the respective stakeholder agencies. The IPCU is staffed primarily by professionals with technical experience in earthquake, civil, structural, geotechnical, electrical, or mechanical engineering who review building and construction designs for quality assurance.

Implementation Guidelines for Retrofitting

Since the building code at the time of the 1999 Marmara earthquake lacked specific requirements for upgrading existing structures, comprehensive guidelines for strengthening structures had to be developed for each type of public building, with an emphasis on schools and hospitals. Key provisions of the implementation guidelines included, for instance, instructions for data collection and technical procedures to determine the appropriate strengthening method. Most of the buildings had no existing documentation, and entire datasets were developed by teams of engineers—both local and international experts—based on site surveys, construction documents, material testing, and soil investigations. The building code was completely revised and updated alongside the implementation guidelines.

Collaboration with International Consultants

A collaborative arrangement between Turkish engineers and international engineering firms leveraged the relative strengths of both groups. Local engineers are familiar with local design and construction practices and can readily identify vulnerable structures, while international consultants may have

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28 The information in this subsection is from Alaluf 2013a.
29 The information in this subsection is from Aluluf 2013b.
more diverse experience in large-scale, cost-effective earthquake strengthening and be able to identify deficiencies quickly in proposed retrofitting schemes, having worked on similar projects. Throughout the implementation phase, international engineers reviewed, or directly participated in the development of, the building designs to ensure the robustness of the structural plans and calculations. They also provided oversight during the construction phase.

An integrated approach to disaster risk management and strong ownership and commitment at national, regional, and local government levels have been vital to the sustainability and success of ISMEP. In parallel to initiatives of the central government, considerable efforts and resources have been invested at the regional and local levels to better prepare at-risk communities for future disasters. A number of governorships and municipalities have taken the initiative to upgrade local emergency response systems, conduct seismic microzonation studies, and initiate planning processes that incorporate natural disaster risk. For instance, Istanbul Province has initiated numerous earthquake risk assessment and planning activities in collaboration with national and international experts. The Earthquake Master Plan for Istanbul, in particular, has been highlighted by the international community as a useful strategic instrument for addressing earthquake risks in highly vulnerable megacities.

Since the devastating 1999 Marmara earthquake, Turkey has been able to enhance its overall resilience to natural disasters significantly through an integrated disaster risk management system with structural, financial, legal, and regulatory measures that complement each other. In 2000, the government established the Turkish Catastrophe Insurance Pool (TCIP), a public–private partnership with the domestic insurance industry that provides earthquake insurance to homeowners (Gurenko et al. 2006). The government made earthquake insurance compulsory for homeowners and abolished its legal obligation to finance the reconstruction of residential dwellings in the aftermath of an earthquake. This move successfully institutionalized a system that holds homeowners and the private sector financially accountable for the risk they incur. The government also enhanced its building codes and construction supervision standards. As a result, the TCIP increased catastrophe insurance coverage from less than 3 percent of residential buildings to 23 percent nationwide and over 40 percent in urban areas. As of January 2014, the TCIP had sold more than 6 million policies, compared to only 600,000 covered households when it was initially set up. The TCIP has paid out nearly 21,000 claims to date, totaling over US$70 million.30

Indonesia: Pilot Implementation in the Education Sector

The frequency and magnitude of extreme hazard events, including earthquakes, tsunamis, volcanoes, and landslides, are increasing around the world, taking many lives and damaging many buildings, including schools.31 In Indonesia, which is among the top thirty-five countries for mortality risks from multiple hazards, about 40 million students go to school in areas at risk of earthquakes, and approximately 75 percent of schools are located in hazardous areas.

While the government of Indonesia has made successful efforts to increase awareness of disaster risk since the 1990s, the devastations of the December 2004 Indian Ocean tsunami and the signing of the Hyogo Framework for Action in 2005 were catalytic toward development of disaster risk management measures and regulations, including enhancing the structural resilience of critical buildings against natural disasters.

30 For more information, see http://www.tcip.gov.tr/zorunlu-deprem-sigortasi-istatistikler.html.
31 Unless otherwise specified, the information in this section is from Fauzan 2013.
In 2011, with funding from the World Bank, the government of Indonesia established the National Secretariat for Safe Schools and initiated the low-cost, five-month Safe Schools Pilot Project to test the cost-effectiveness of a quick and simplified local-level structural strengthening initiative. The project was designed in part to support the National Secretariat for Safe Schools, along with the Ministry of Education and Culture and the National Agency for Disaster Management, in developing safe school guidelines involving both structural principles (concerning school rehabilitation and retrofitting to meet the standards for safe and resilient buildings) and nonstructural principles (concerning school communities’ ability to identify potential risks and prepare for a response).

**School Selection**

The guidelines developed under the Safe School Pilot Project were implemented in a total of 180 schools, spread over three provinces that had recently experienced deaths and heavy damage to school buildings from earthquakes and tsunamis: West Java, West Sumatra, and West Nusa Tenggara. The district education office of each province selected sixty schools based on the following key criteria: need for rehabilitation, vulnerability to natural disasters, and location of the schools and their proximity to one another. Given the short duration of the project and the budgetary constraints, the distance of the schools from the home base of the pilot project teams also factored into prioritization.

**Local-level Implementation**

The project teams comprised technical and social facilitators chosen from the community to provide assistance to the sixty schools in each pilot province. The project trained both technical and social facilitators, the former in repair and retrofitting of school buildings and the latter in early warning and disaster evacuation systems. Training sessions focused on simple retrofitting techniques with low-cost local materials, such as chicken wire mesh, whose use could be easily understood by local workers (see figure 3.3). Pilot schools established disaster preparedness committees and regularly conducted evacuation simulations based on standard operating procedures and guidelines.

**Figure 3.3**

Strengthening Old Unreinforced Masonry Walls with Chicken Wire Mesh and Tie Beams

*Source: Fauzan 2013.*
**Outputs of the Pilot**

The pilot produced the following outputs:

- Simple guidelines on school retrofitting to guide school rehabilitation design and construction
- Establishment of school disaster preparedness teams
- A standard operating procedure for evacuation, including an evacuation map for each school, and regularly conducted evacuation simulations
- Various media for safe schools, including posters and books about disasters
Since 2010, the GoP has aimed to develop a comprehensive agenda that addresses the institutional, legal, physical, and financial dimensions of disaster risk management. To this end, the DPWH, in cooperation with the World Bank, has developed the following:

- A set of guidelines for the seismic evaluation of schools and hospitals in Metro Manila
- A technical manual and methodologies for prioritizing buildings to identify the highest risk candidate structures for upgrade and risk reduction
- Tailored design examples for upgrading a typical school building in Metro Manila

The results of the prioritization show that strengthening the most vulnerable 5 percent of school buildings (186) can reduce the number of student fatalities by 25 percent (more than 6,000 lives saved). By strengthening the most vulnerable 40 percent of school buildings (1,466), potential student fatalities can be reduced by 80 percent (more than 19,000 lives saved). In other words, upgrading a relatively small number of systematically selected structures can save a disproportionately large number of lives, and it would be more cost effective than building new schools.

As a result of these findings, the DPWH committed to implementing the cornerstone phase of a Safe and Resilient Infrastructure Program in Metro Manila. This would involve upgrading approximately 200 of the most vulnerable public school buildings in Metro Manila, with a view toward eventually scaling up to other sectors (for example, lifeline infrastructure) and geographical locations and to institutionalizing quality assurance systems. As the GoP formulates an initial strategy for undertaking its earthquake risk management program, international experience can provide insight into the potential challenges and key lessons of developing and implementing structural resilience programs at various scales.

Moving forward with the implementation of a cornerstone phase of the Safe and Resilient Infrastructure Program will depend on the active support of stakeholders, including the affected communities and public institutions; local and national government agencies; and the practicing technical community. Stakeholder advisory workshops can help maintain close coordination and instill ownership among government agencies and technical organizations involved in the program.

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32 From the MMEIRS M7.2 scenario earthquake along the West Valley Fault.
33 Generally, experience shows that five to seven schools can be strengthened and renovated for the cost of one new building.
Furthermore, communication and training can help raise awareness within the local community on the severity of earthquake risk in Metro Manila and the degree of potential financial and human impact that can be mitigated by an earthquake strengthening and upgrading program. Overall, integrating the following key messages into the implementation strategy will be essential:

- An integrated approach to earthquake risk management can strengthen key buildings and infrastructure and reduce the damaging effects of future disasters in the Philippines.
- Earthquake risk management and strengthening programs initiated by both the public and private sectors in many countries have often consisted of three phases—risk audit, risk assessment, and implementation.
- Several key technical components must be considered in the design of a phased earthquake risk management program, including a prioritization methodology.
References

AIR/ADPC. 2014. The Philippines Catastrophe Risk Profile. AIR/ADPC on behalf of DOF-IFG.


